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31 AUGUST 1999

Date

GRADUATE SCHOOL

MANAGEMENT OF PINE REGENERATION IN ITASCA STATE PARK, 1937-1994

A THESIS
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA
BY

Kristin Louise Snow

In Partial Fulfillment of the Requirements
for the Degree of
Master of Science

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Abstract

The primary interest and attraction of Itasca State Park is and has been pine forests. Regeneration of pine forests has been the highest management priority since soon after the Park's establishment, but little pine regeneration has resulted from the management efforts. Unfortunately, records of the work are limited and were uncentralized.

I gathered as much of the scattered management information as possible and created a computerized database to organize this information. The database design includes a classification of treatments and a system of tracking the spatial relationships of land units. The data will be used by Park personnel for planning, and the database structure will be used to track ongoing management work. The collected management history of the sites, and the design of the database, are presented here.

I visited a subset of the sites to determine the status of pine condition and abundance, and I examined this recent status of these sites in relation to the management work that had been done. According to my criteria, 29% of the sites had a promising amount of pine regeneration. These criteria, based on pine density, age, and condition, were generous. Individual treatments that appear to have been beneficial to pine regeneration are planting, exclosure, and release by brush removal. Conditions and treatments that appear to have been detrimental to pine regeneration are overstory and prescribed fire. Promising units were either planted and had no canopy, or were fenced, planted, and had a scattered pine canopy. Follow-up in the form of protection, release, and additional propagation was important to pine regeneration.

My recommendations include: restore larger sites; document goals and activities more carefully; experiment more with fire; control deer; use more release; increase efforts towards the regeneration of white and jack pine, relative to red pine; and use more follow-up.

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Introduction

Itasca State Park is a 32,000-acre state park in north-central Minnesota in Clearwater, Hubbard, and Becker Counties. It lies on the transition zone between coniferous and deciduous forest and is close to the prairie-forest border. Though the landscape of Itasca is a mosaic of vegetation types, the primary interest and attraction of the Park is, and has been, pine forests. It is currently one of the few places in the state with old-growth pine forests. The Park has a legal mandate (General Laws of 1907, Chapter 90) to "preserve intact the primeval pine forest," but Park managers have had difficulties in doing so.

The first tree planting in the Park took place in 1902, 11 years after establishment (Dobie 1959). Planting became more extensive in 1909 when the University of Minnesota Forestry School took over forest management work. The early work was primarily in public areas, and it was probably typical management for the time rather than managers' responses to a perceived problem. The first record of concern for the future of pine in the Park seems to be in the mid-1930s when there was "a rash of plans formulated by foresters for the management of the timber of Itasca Park. All of these plans agreed that the pine areas were being reduced…and that there was no pine reproduction," (Dobie 1959).

Pine restoration has been a priority management objective ever since. *Pine restoration* is defined here loosely as any management activity intended to increase the regeneration of pines—red (*Pinus resinosa*), white (*P. strobus*), or jack (*P. banksiana*)—in the Park, with the assumption that this is the first step towards a restoration of pine communities. (I am unaware of any attempts to restore the non-pine aspects of pine communities.)

The problem is a low success rate of these restoration attempts. This rate has never been calculated, as far as I know, but it has also never been disputed that a strong majority of attempts have been unsuccessful. The assertion that natural regeneration has been inadequate to replace the old-growth pine forests as the pines age and die has also never been disputed, as far as I know.

Unfortunately we know of some restoration attempts only through evidence of manipulation in the field. Records do exist for other attempts, but they have been scattered through the years. There has been no central place for maintaining these records, nor for organizing the efforts of the various organizations and individuals working independently towards the cause of pine regeneration.

The purpose of my work was to bring together as much information as possible and to learn more about what has and has not worked to regenerate pines. Specifically, the purposes are:

- to gather together as much of the scattered management information as possible (Chapter 1),
- to create a computerized database and paper filing system to organize this information and any newly acquired information (Chapter 1),
- to determine the current status of the restoration sites (Chapter 2), and
- to analyze the database to make generalizations about what methods have been used, which have worked, and which have not (Chapter 2).

I. Chapter 1: Management History of Itasca State Park

I.A. Introduction

Many agencies and individuals have been involved in natural resource management—consisting primarily of pine restoration—in Itasca State Park. These people and agencies I call collectively "**Park managers**," meaning any person or agency directly affecting the natural resources management of the Park. They include:

- Civilian Conservation Corps
- Minnesota Division of Parks
- Minnesota Division of Forestry
- University of Minnesota School of Forestry, College of Biological Sciences, and Itasca Forestry and Biological Station

Often these agencies worked independently, and all had responsibilities beyond the resource management of Itasca Park. In most cases management records were stored only by the agency or individual, if they were kept at all. Too often, because of personnel changes, office moves, or agency reorganizations, records were destroyed or lost. Because there was no central location for management records, it has been difficult to know what was done to a particular area, and impossible to look across all management activities to guide future management decisions. The inconsistency in management philosophies and lack of a cohesive management program through time may be an important reason for the low pine regeneration rate on managed sites.

The situation improved in 1994, when a new position, Itasca State Park Natural Resources Specialist, was created. This employee, Becky Marty, is responsible solely for Itasca Park. Her work is not included in this thesis, which ends with work done in the spring of 1994.

My task was to create a database for central storage of management records and fill it with as much management history as I could find. The database is intended as a tool for future management decisions in Itasca State Park. The specific objectives are:

1. To provide a centralized place for storage of management history and new activities as they occur, and
2. To allow for analysis of past activities, to support better decisions in the future. An analysis of the database is provided in Chapter 2.

Although the database is intended to be used for any natural resource management activities in the Park, the management history presented here consists almost entirely of pine restoration activities.

I.A.1. History collection

I collected documents from various agencies and individuals and interviewed several individuals. These agencies and individuals include:

- Itasca State Park, especially Ben Thoma (Park naturalist and historian) and Becky Marty (Park Resource Specialist)
- DNR Parks, especially Paul Rundell (Resource Specialist of Northwest Region)
- DNR Forestry (Bagley, Bemidji, and Park Rapids Area Offices)
- University of Minnesota School of Forestry, especially Prof. Vilis Kurmis and Prof. Henry Hansen; College of Biological Sciences, especially Prof. John Tester and Prof. Don Lawrence; and Itasca Forestry and Biological Station, especially Jon Ross (Station manager)
- theses and publications from the University of Minnesota and other universities

Most information is from Paul Rundell, in the form of memories, documents, and field observations from circa 1980 to 1994. As much of his information is from memory, the accuracy is uncertain.

Appendix 1 is a complete list of database sources.

A subset of sites, called *treatment units* (described and analyzed in Chapter 2), was visited in the field. I made site maps on overlays of aerial photographs (approximately 1:26,000 scale), and attempted to delineate the application extent for treatments applied to only part of the site (*subsites*). The overlays are not included in this thesis but will be given to the Park; they may be digitized by Park personnel. During the visits I also attempted to validate dubious or vague treatment records.

I.A.2. Creating the Database

I.A.2.a. Design

A database is a model of the real world. The database design of Itasca management history must represent management activities, where and when they were done, and the sources of information. I designed a relational database to do this in Microsoft Access 2.0. A relational database is a database in which data about different subjects or entities are stored in separate tables, and the relationships among the entities are defined.

To enter information in a repeatable way in the database, I had to classify certain aspects of management work. In particular, I categorized treatments so they could be consistently entered and analyzed, and I divided the land into **sites** on which treatments occurred.

The design needed to be flexible to accommodate both very sparse and uncertain records and highly detailed information, and to accommodate the needs of management planning and history analysis. I tried to make the database as simple as possible for the users (Park managers), and I added a user-interface to make common tasks easy to do and ensure consistency in future data entry.

I.A.2.b. Data entry

I looked at all the information for each site and entered the treatment details. As described in the database design section, I divided sites into subsites as needed, based on the actual location of treatment applications.

There is a huge range of confidence and completeness in the data for sites. For most sites, the data have many gaps and questions. Frequently two sources for the same event contradict each other. I tried to enter what I thought was the best information, based on the relative reliability of the sources and common sense; sometimes I had to guess. I recorded my confidence for each record, recorded the sources contributing to each bit of information, and described contradictions and other questions about the data.

I.B. Results: Design of database

I.B.1. Overview

The basic components of the management history database are **sites**, the physical units of land which are managed, and **treatments**, the activities which are done to the sites. The combination of the two—the instance of a treatment being applied to a site—I call a **treatment event** (Table 1).

Table 1. An example of a simple treatment event.

EventID	1052
Date	May 16, 1957
Site	Lake Alice Trail
Treatment	Planting
Stage	Propagation
Confidence	High
Purpose	Experimental planting on clearcut aspen site.
Result	Apparently good survival.
Details	625 RP/acre, 438 JP/acre, 500 WS/acre
Sources	Hansen 1969 (year, only mentions RP and WP; Hansen 1970 ("spring 1957," species); Hansen *et al.* 1974 (year, species); MN Forestry Planting Record (All. Totals 1,000 RP, 700 JP, and 800 WS)

The database stores information about:

- Units of land (**sites**) in the Park, and their spatial relationships
- The kinds of **treatments** that have been used in the Park
- Treatment applications to sites (**treatment events**)
- Results of site **monitoring** (monitoring is considered a type of treatment)
- **Sources** of the information

A collection of related information about a subject or entity in a relational database is called a *table*. Site, Treatment, and Treatment Event are separate tables in the database; additional tables support them. The database tables and their relationships are shown in Figure 1 and are described below.

Information can be displayed in various ways, such as a list of sites to which a given treatment occurred, or a sorted history of what occurred to a particular site. There are basic queries of the data, forms for viewing and editing data, and reports for printing. These kinds of functions can be modified and added to by Park staff.

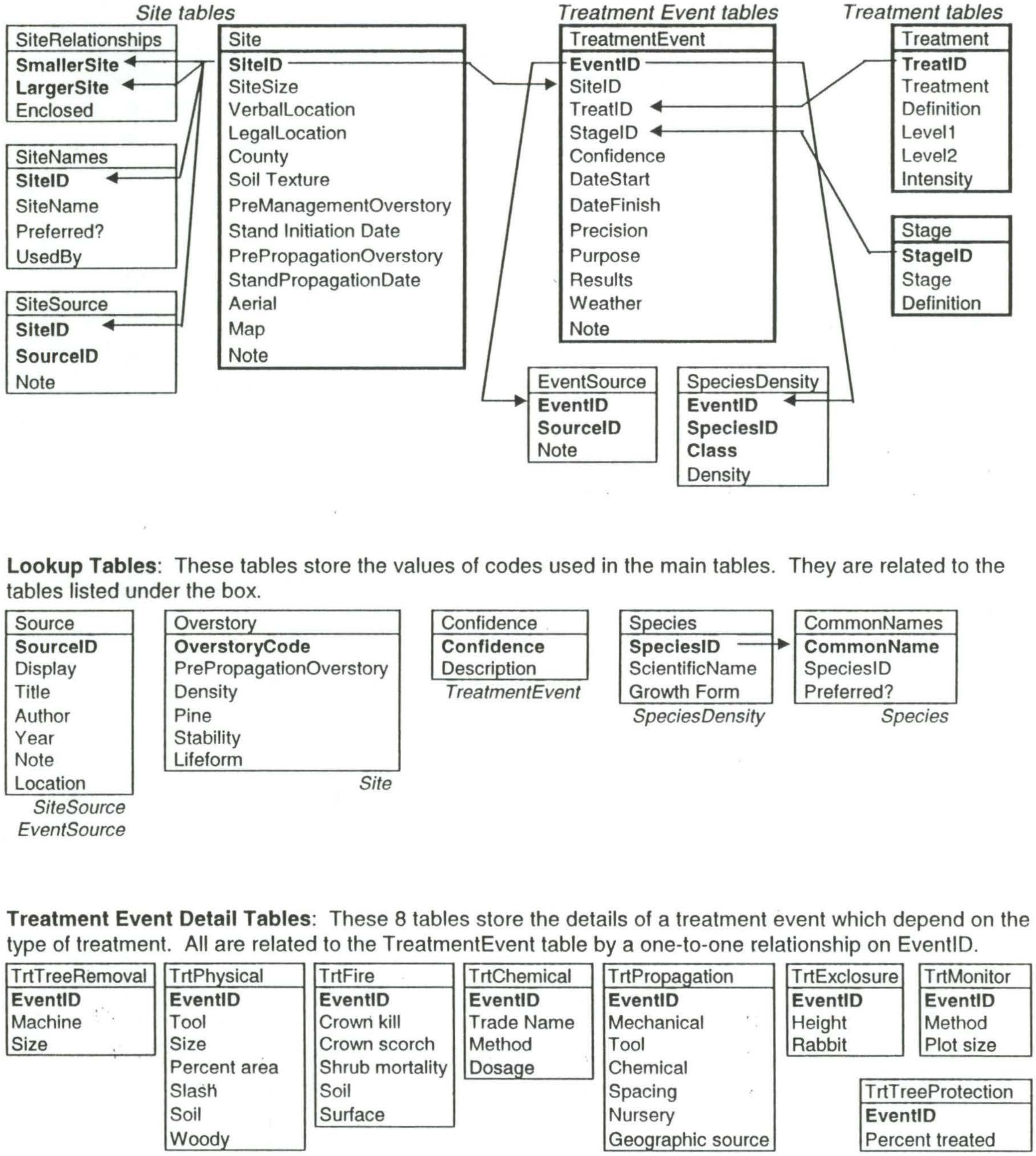


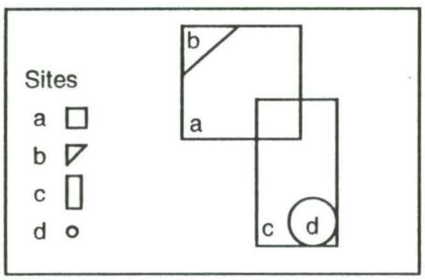
Figure 1. Design of the management database. Each box is a table in the database; the table name is shown above the line and the fields (attributes) are listed below. The primary key is in boldface. Relationships are shown by arrows; the arrow points from the one to the many side of the relationship. The 4 main tables are shown with a thick border. See text for a description of the tables and their attributes.

I.B.2. Sites

Sites are discrete, mappable units of land on which management treatments occurred. Each treatment is done to a specific space on the ground, and this space defines the site. More than one treatment event (and different treatment types) can occur on a given site.

I.B.2.a. Site relationships (supersites, subsites, and overlapping sites)

Sites can share land area with other sites (Figure 2). The most common relationship is that one site occurs completely within another site. For example, a 10-acre area may be logged, and only 5 acres of it planted to pine. The planted area is a **subsite** of the logged area, and the logged area is a **supersite** of the planted area. In most cases there is only one supersite with multiple subsites, but there are a few instances of site relationships of more than 2 levels. Sites can also overlap, *i.e.*, the sites share land area but neither site encloses the other. The spatial relationships between every pair of sites sharing land area is stored in the database, with an "enclosed" attribute having the value "yes" or "no" (Figure 2).



Site relationships

Smaller site	Larger site	Enclosed?
b	a	yes
a	c	no
d	c	yes

Figure 2. Example of site relationships. In this example, b **is a subsite of** a, d **is a subsite of** c, **and** a **and** c **overlap. All treatments of** a **were also done to** b **and to part of** c; b **had additional treatments than those done to all of** a, **but all treatments done to** b **were done to** ***part*** **of** a. **The table shows how these relationships are stored in the database: all combinations of intersecting sites are listed, and if the site in the first column is fully enclosed by the site in the second column, a "yes" is entered. If 2 sites are not enclosed, which is entered as smaller or larger is immaterial.)**

A treatment is entered only for the exact site to which it occurs; the site defines the land area to which the treatment was applied. However, the treatment also occurred to all related sites, that is, it occurred to *all* of any site encompassed by the entered site (any *subsite* of the site) and to *part* of any site which encloses the entered site (a *supersite* of the site) or overlaps with the site (Figure 2). The site relationships stored in the database are used to link a treatment that occurred to one site to all sites that share land area with this site. In the example in Figure 2, site *b* is a subsite of site *a*. A treatment applied to site *a* is listed only for site *a*; it would be redundant to list it for site *b*. Instead, the information that site *a* encloses site *b* is entered into the database, and this information is used when displaying treatments for site *b* (*i.e.*, treatments entered for site *a* are included in the list for site *b*). Treatments entered for site *a* are also listed as occurring to *part* of site *c*.

The concept of sites and their relationships is purely one of spatial location. If all the sites were entered into a Geographic Information System (GIS), the relationships would not need to be stored in the database (although it might still be convenient). Instead the GIS capabilities could be used to determine what treatments were performed to an area of interest. I have attempted to make the database compatible with GIS in hopes that someday someone will digitize the sites.

I.B.2.b. Sites vs. traditional sites, projects, and treatment units

My concept of site differs somewhat from what has been used traditionally by Park managers. A manager's "site" name was initially used to refer to a discrete unit of land area, often defined by the original felling operation. However, subsequent treatments attributed to the "site" did not necessarily occur to that exact land area. The traditional concept of "site" is more similar to my concept of **supersite**, except that subsites were not defined.

In order to separate the concepts of exact spatial location (my *site*) and the traditional "site," I call the traditional sites **projects**. A project is not necessarily a mappable location but is rather an attempt at regeneration. However, my definition of project is broader than a supersite; any group of sites used to test a certain method or question are a project, even if the sites are not spatially related. In this way, projects can be hierarchical.

Treatment units are a selection of sites (which may be subsites or supersites) which I thought would be useful to compare in analysis. They are not a necessary part of the database for tracking management history. They are included in the database and are described and used in Chapter 2.

I.B.2.c. Site Names

Most traditional "sites" were named based on a nearby location or the purpose of the project. I have tried to retain these names as names for supersites. However, because of the number of different managers working at Itasca over the years, more than one name has been assigned to most supersites. Therefore I chose what I considered to be the most commonly used name and assigned it as the *official name* for each supersite. The other names that have been used are stored as *alternate names* in the database.

Subsites are given the name of their supersite followed by 2 hyphens and a qualifier. For example, the fenced portion of site "Jack Pine 1" is named "Jack Pine 1–Fenced." The correct identification of site relationships does not depend on the naming scheme, and therefore it is not imperative that new sites follow this convention. All supersites also have a 3-letter code, such as JP1 for "Jack Pine 1," and subsites have a 4-letter code (JP1F for "Jack Pine 1–Fenced").

I.B.2.d. Attributes of Sites

Site attributes are stored in the tables Site, SiteNames, SiteRelationships, and SiteSource (Figure 1). The basic attributes (fields) are:

- the preferred **name** and alternate names of the site,
- the approximate **size** (in acres) of the site,
- a description of the **location** of the site,
- the source of the best **map** or sketch of the site,
- the code for the 1990 black-and-white **aerial** photograph on which I traced the site (see p. 4),
- the **spatial relationships** of this site to sites which share land area,
- **soil texture** (when available),
- the date the site was first managed (***stand initiation date***),
- composition of tree canopy before management (***premanagement overstory***),
- the date the site was first propagated (***prepropagation date****;* used to calculated the current age of the stand),
- condition of tree canopy, in terms of tree canopy cover and presence of pines, at the time of propagation (***prepropagation overstory***, Table 4, the same as *overstory code* used in Chapter 2),
- the **sources** of information about the site, and
- **notes** about the purpose of the site.

I.B.3. Treatments

A treatment is anything done to a site. Usually it is a resource management activity, but it can also be a natural event such as a wildfire or natural seeding, an economic activity done prior to Park ownership of a site, or any other activity.

In order to enter treatments in the database in a consistent way that allows for analysis, treatments had to be categorized. I classified them in two ways.

I.B.3.a. Classification by stage

I first classified treatments into the stages of a traditional rotation:

1. **Site preparation** is any treatment that prepares the site for propagation. Although ***harvest*** could be considered a separate stage in a traditional forestry system, it is used in Itasca as a tool to prepare a site for propagation. I therefore include it under *site preparation* and call it *felling* rather than *harvest.*
2. **Propagation**[1] is any treatment that adds target species to the site ("artificial regeneration" in the form of seed, seedlings, or transplants; or "natural regeneration").
3. **Release** is any treatment that reduces competition around existing individuals of the target species. Release includes *thinning*, which reduces intraspecific competition.
4. **Protection** is any treatment that protects existing individuals of target species from potential agents of damage, disease, or death.
5. **Monitoring** is any survey of any aspect of the site.
6. **"Other"** is the "stage" I used for entry of activities or events that are unrelated to, or a detriment to, pine restoration. Some natural events and economic activities were placed into this category (see below). All treatment events in the "other" category were excluded from the analysis in Chapter 2.

These stages are semi-chronological, that is, site preparation, propagation, and release occur in that order, while protection and monitoring occur at any time during a rotation.

Despite the silviculture basis of this model, it proved useful for classifying and understanding the treatments that have so far occurred at Itasca. This is not surprising, because forest restoration work has been based on forestry practices. If restoration activities drift further from their forestry origins, then a new classification model may be needed.

My use of stage does not necessarily refer to the manager's intentions. Indeed a natural, economic, or accidental occurrence can still be assigned to a stage if 1) a manager took advantage of it, or 2) its results had the effect of a stage, as if a manager had intended it. The following are the guidelines I used to assign stage:

---

[1] The term propagation is used by most foresters in reference to greenhouse activities only, while "regeneration" is used for planting, seeding, and so on. However, the concept of regeneration is broad enough to include the growth of the trees on the site (this is the sense in which I have used the word), so I chose to use "propagation" to refer very specifically to the act of adding species to the site.

- *Natural events* were entered as site preparation or release if the manager "took advantage" of what happened, or if "desirable" conditions resulted. Of course, natural seeding was entered as propagation. If the occurrence caused damage, or served no "purpose" as far as regeneration is concerned, then the treatment was assigned to "other" stage.
- *Economic activities* (such as farming) were entered as site preparation if they resulted in an old field or other open area that precluded the need for tree and shrub removal—though often the manager was not "taking advantage" of this situation, but trying to revegetate the site. Turn-of-the-century logging activities were entered as "other," because (1) they needed to be excluded from analysis (though many sites are second growth, the first logging has not been entered for most), and (2) they resulted in aspen forests that have made pine regeneration more difficult.
- When artificial propagation was not used it was sometimes difficult to distinguish site preparation from release. Such treatments were entered as site preparation if the manager was primarily trying to stimulate natural regeneration, even if some existing regeneration may have benefited. They were entered as release if the manager noticed significant existing natural regeneration and decided to help it along; the activity may have also stimulated new regeneration, but the primary objective was to release existing vegetation. If there are no notes as to manager's intentions or the extent of existing natural regeneration, then I assumed the treatment to be a site preparation.
- In a few cases I could not select a stage due to lack of information. I did not assign these events to "other"—a category which requires information—instead I left stage blank.

<u>Attributes of stage</u>
The only attribute (field) of a stage is:

- the **definition** of the stage.

I.B.3.b. Treatment types

Stage is not a fine enough grouping of treatments; within each stage a variety of activities may occur. I could find no finer groupings of treatments in the literature, so I developed a 3-level classification that is specific to the needs of this project. The categories in each level are called **treatment types**, or "treatments" for short. Although stages are also treatments, it is useful to call them *stages* and reserve the word *treatment* for treatment types.

Although stages are a broader grouping than treatment types, my classification is not nested within the stage classification. Any treatment type can be used within any stage, for example, herbicide application is a treatment that may be applied as site preparation or release.

In the categorization of treatments I considered the purpose of the treatment, the immediate results of the treatment, and tools used. The result of the treatment was weighed most heavily, because intentions may differ from what actually happens. The process necessarily involved interpretations and assumptions about what aspects of the treatments are most important.

I tried to find a balance between the flexibility needed to report details (or not, when they are not known) and variations in treatment methods, and the rigidity needed to have consistent treatment types to compare across sites and years. As a result, the classification is hierarchical. The broadest grouping (Table 2, Level 1) allows the details of treatment events to be stored in separate tables based on similarity of the kinds of attributes (fields) recorded for each treatment type (see Figure 1). The next grouping level (Table 2, Level 2) was used for the analysis in Chapter 2; the finest categorization (Table 2, Level 3), which is the level actually entered into the database, is too fine to allow for much "replication" in analysis.

Table 2. Treatment classification. The treatments are grouped into 3 levels, shown from broadest to finest. The purpose of each level is shown in the column heading. Intensity, a treatment rank used in analysis, is described in Chapter 2. In Level 2 (Analysis), blank rows are treatments that were not included in analysis; these also have an intensity rank of 0.

Level 1 (Treatment detail tables)	**Level 2** (Analysis)	**Level 3** (Database entry)	**Intensity** (Analysis)
Chemical	Herbicide	Herbicide	4
Exclosure	Exclosure	Install deer exclosure	1
Exclosure		Install rabbit exclosure	0
Fire	Prescribed fire	Prescribed fire	2
Fire	Wildfire	Wildfire	2
Monitor		Archaeological survey	0
Monitor		Monitor	0
Monitor		Monitor physical environ.	0
Monitor		Monitor plant community	0
Monitor		Monitor small mammals	0
Monitor		Monitor target species	0
Monitor		Small mammal exclosures	0
PhysicalDisturbance		Added fill	6
PhysicalDisturbance	Blading	Bladed	6
PhysicalDisturbance	Brush removal	Brush removal	1
PhysicalDisturbance	Cultural	Cultivation	5
PhysicalDisturbance	Cultural	Development	5
PhysicalDisturbance	Cultural	Mining	5
PhysicalDisturbance	Mechanical site prep	Disking	6
PhysicalDisturbance	Mechanical site prep	Furrowing	6
PhysicalDisturbance	Mechanical site prep	Grubbing	6
PhysicalDisturbance	Mechanical site prep	Mechanical Raking	6
PhysicalDisturbance	Mechanical site prep	Mechanical Rolling	6
PhysicalDisturbance	Mechanical site prep	Mechanical Scalping	6
PhysicalDisturbance	Mechanical site prep	Shearing	6
PhysicalDisturbance	Skidding	Whole-tree skidding	0
Propagation	Natural seeding	Natural seeding	0
Propagation	Planting	Planting	2
Propagation	Seeding	Direct seeding	1
TreeProtection		Install tree shelters	2
TreeRemoval		Blowdown	3
TreeRemoval		Thinning	0
TreeRemoval	Felling	Felling	3
Other		Cancel burn	0
Other		Exclosure repaired	0
Other		Maintain fire break	0
Other		Remove exclosure	0
Other		Slash fire	0

Treatment definitions

The treatments shown in Table 2 are defined here, grouped by Level 1 types. Level 2 (underlined) is shown only if different from Level 3.

CHEMICAL

Any chemical treatment of a site, excluding fire but including herbicide, fungicide, and insecticide. At Itasca, only herbicide has been used.

- **Herbicide**: Chemical preparation used to kill or inhibit growth of certain plants or their propagules.

EXCLOSURE

A fenced area or cage enclosing vegetation and keeping out animals.

- **Install rabbit exclosure**: Install fencing with mesh small enough to keep out rabbits. Often applied to the lower portion of a deer exclosure. Not currently used.
- **Install deer exclosure**: Install a fence to keep deer out of an area.

FIRE

A fire on the site, prescribed or natural. Does not include slash fires, which are classified under "other."

- **Prescribed fire:** Controlled application of fire under such conditions of weather, fuel, etc. as to allow fire to be confined to a predetermined area and also produce the fire behavior required to meet certain objectives.
- **Wildfire**: A fire started by lightning or accidentally by humans.

MONITOR

To evaluate a site for vegetation (target species, competition, or others), damage, or other attributes.

- **Archaeological survey**: A survey for evidence of past human activities; these must often be done before any site manipulation.
- **Monitor physical environment**: Measure physical aspects of the site, such as soil type or nutrient availability.
- **Monitor plant community**: Estimate aspects of the plant community of the site, such as species composition or biomass.
- **Monitor small mammals**: Monitor small mammal populations or other small mammal data. Does not refer to installation of exclosures.

- **Monitor target species**: Estimate the condition, density, or other aspects of the target species of the site.
- **Small mammal exclosures**: Install and monitor the effects of small mammal exclosures (small cages, typically 1 m^3). These exclosures have only been used for rodent predation research, and are therefore not protection. Rabbit fencing, which is used only to protect seedlings, is included separately under protection.

PHYSICAL DISTURBANCE

General term for treatments which physically (as opposed to chemically) disturb the soil or ground vegetation. Can be done mechanically or with hand tools.

- **Add fill**: Add soil, gravel, or other material to build up an area, usually where the soil has been previously removed.
- **Blading**: A treatment that was tried only once (to SLEW). The blade of a bulldozer was lifted about 1 foot off the ground and driven back and forth across the site to knock down the aspen.
- **Brush removal**: Removal of brush by hand

Cultural: A physical disturbance for economic reasons, such as farming and road building.

- **Cultivation**: Mixing of organic and mineral soil layers, involving motions which force down and lift soil (deeper than disking). I use this term only in the sense of spatially continuous preparation of a site for agriculture; some mechanical site preparation can cultivate soil, but to my knowledge this kind of site preparation has only been applied in patches or strips in Itasca, and these activities are classified under the specific mechanical site preparation treatment.
- **Development**: Modification of a site for human use (not including cultivation), including road and structure building.
- **Mining**: Removal of material out of the ground for economic purposes; in Itasca this has usually been gravel mining, and old gravel pits have been revegetated.

Mechanical site preparation: Using a machine to disturb the soil in preparation for planting.

- **Disking**: Breaking up the ground with disks which roll over the soil. A site is typically treated in its entirety, and often is "cross-disked," treated twice, the second time in a direction perpendicular to the first. Not as deep as cultivation.
- **Furrowing:** Creating a shallow trench or furrow in which to plant trees, usually accompanied by a mixing (cultivating) of the soil within. A trench is deeper than a furrow,

but the terms are typically used synonymously. No longer used because apparently deer follow the furrows and eat the seedlings one by one without having to look up.

- **Grubbing**: Felling by exposing and cutting roots, typically done to shrubs.
- **Mechanical Raking**: Pushing large objects like slash, tree roots and rocks off a site, leaving smaller stones, earth, etc. in place, using blade with scarifier teeth instead of a plain edge. Incorporates duff into soil.
- **Mechanical Rolling**: Mechanically flattening and breaking up woody cover. May tear up roots of shrubs and saplings and cultivate (but not scrape away) the soil. Usually consists of 1 or 2 steel drums with attached blades, pulled by a tractor (for example, a 9-ton roller pulled by a D-7 Cat). Also called drum scarifier and roller-chopper.
- **Mechanical Scalping**: Using a machine to pare off patches of low and surface vegetation, together with most of the roots, to expose a weed-free soil surface. Done before seeding or hand planting or during machine planting.
- **Shearing**: Moving and clearing all standing material (shrubs, stumps) at ground line using a shear blade on a large tractor (bulldozer). Can move considerable soil as well, but duff can resettle. Pulls out shrub roots if done in winter ("winter shearing").

Skidding: Dragging logs or whole trees from stump to a loading dock. It can scrape away litter and expose bare soils (in shallow furrows) if the forest was free of brush before cutting. Although part of the harvest stage, its effect is really that of site preparation.

- **Whole-tree skidding**: Most skidding in Itasca has been "whole-tree," which means the entire tree, with its crown and sometimes its roots, is skidded, as opposed to the delimbed bole or its bucked pieces. The branches plow small furrows.

PROPAGATION

To assist in the reproduction of desired species in a desired location, by planting, direct seeding, or allowing for natural seeding.

- **Natural seeding**: Allowing for natural seed dispersal from nearby trees. Assumes that the site has been prepared to enhance chances of germination and that an adequate seed source has been observed.
- **Planting**: Seedlings grown in greenhouses or outdoor nurseries are transplanted to the site.
- **Direct seeding**: Artificial dispersal of tree seed. Seeds may be treated with chemicals to repel rodents and birds.

TREE PROTECTION

Individual protection of trees, including tree shelters, staking, and budcaps.

- **Install budcaps**: Staple folded pieces of thick paper over the buds of seedlings or saplings, to protect them from herbivory by deer.
- **Install tree shelters**: Tree shelters are plastic tubes placed around seedlings or transplants at the time of planting, used to protect the trees from herbivores (and human feet) and to increase the microenvironmental temperature for faster growth.
- **Stake**: Support and protect a tree with stakes, typically three. Used only in public areas.

TREE REMOVAL

General term for killing of trees (including cutting and girdling), which may or may not include their removal from the site.

- **Blowdown**: The falling of trees due to intense winds.
- **Felling**: Cutting and removing trees. (The tree removal is technically a separate step, and is usually Skidding.)
- **Thinning**: Cutting to reduce stand density so that growth of remaining trees is accelerated. Cut trees are typically the same species and age as those that remain.

OTHER

- **Cancel burn**: Cancel a planned burn; it is important to enter such information in the database so that (1) the planning records are not confused for records of what actually happened, and (2) the reasons for canceling the burn can be entered.
- **Repair exclosure**: Repair an exclosure to maintain its effectiveness.
- **Maintain fire break**: Any natural or constructed barrier utilized to segregate, stop, and control the spread of fire or to provide a control line from which to work.
- **Remove exclosure**: Taking down an exclosure after it is no longer needed, or for other, usually economic, reasons.
- **Slash fire**: Burning slash (piled or distributed) after felling. Can help control brush and scarify the soil, but usually has little effect and is simply part of the felling operation. Does not have the properties of a prescribed fire.

<u>Attributes of treatment types</u>

In the database, treatment types are assigned at Level 3 of the classification. (This is the level that has a Treatment ID.) The attributes (fields) of a treatment type are:

- the higher-level **groups** (Level 1 and Level 2 groups, see Table 2) under which the treatment falls
- the **definition** of the treatment, and
- the **intensity** rank of the treatment (described in Chapter 2).

I.B.4. Treatment Events

An instance of a treatment being applied to a site is called a treatment event (Table 1). The records in the treatment event table contain the actual management history of the Park. Each record contains the site, treatment, date, and other details about what occurred. If different treatments were applied to one site on the same day, they are stored as separate records.

I.B.4.a. Attributes of Treatment Events

The attributes of treatment events are stored in the TreatmentEvent, EventSource, SpeciesDensity, and 8 treatment detail tables (Figure 1). The attributes (fields) of a treatment event are:

- starting and ending **dates** of the event; the precision of dates varies dramatically in the available sources, so a date, month, season, or year may be entered
- the **site** to which the treatment occurred, defining the land area to which the treatment was applied; other affected sites are automatically linked to the event based on site relationships.
- the **treatment** that occurred to the site; new treatments must first be added to Level 3 of the classification before being entered into a treatment event
- the **stage** that occurred to the site; entered in addition to treatment, because it is a 2-way, rather than hierarchical, classification.
- my **confidence** that the event actually happened (see Table 3 for values); sometimes it is unclear if the record of a treatment event is a proposal or a record of what actually happened, and sometimes it is unclear exactly where or what was done
- the **purpose** of the event, according to the manager
- the immediate **results** of the event (*i.e.*, did it go as expected?)
- the **weather** conditions of interest
- the **sources** of information about the event, along with notes indicating if multiple sources agree and which are more reliable
- the **details** of the event; depending on the Level 1 treatment type (Table 2), certain details can be entered. For example, for a planting, the species, planting density, and planting

method can be entered. The treatment detail tables are Chemical, Exclosure, Fire, Monitoring, Physical disturbance, Propagation, Tree protection, Tree removal, and Other; see Appendix 3 for a description of these tables. A treatment does not need to fit into one of these categories to be entered and new detail tables can be added as the need arises.

- the **density of** each **species** of interest at the time of the event; a species can be entered multiple times for the same event if grouped by *class*, such as an age class, height class, or subsite grouping. In particular, this field is used to enter propagation and monitor densities.
- any other **notes** about the event. This field is rather heavily used, because there is high variability in the kinds of information reported for treatment events.

I.B.5. Lookup tables

Other tables contain the values of codes used in the basic tables. These include:

- **Confidence** values and their meanings (Table 3):

Table 3. Confidence values. Zero is the lowest confidence, and the extremes (± 3) are the highest confidence. Negative values indicate confidence that the event did *not* happen.

Confidence		Description
high	-3	**Tried but it did not happen**
	-2	Very probable that it did not happen
	-1	Don't think it happened
low	**0**	**Uncertain if it happened**
	1	Think it happened
	2	Something definitely happened but uncertain about details; not well documented
high	3	**Definitely happened; well-documented**

- **Prepropagation Overstory** values (Table 4, described in more detail in Chapter 2):

Table 4. Overstory values for prepropagation overstory.

Overstory	Tree Canopy	Dense Canopy	Overstory Code
sparsely vegetated	no	no	1
clearcut	no	no	2
sod	no	no	3
scattered pine	yes	no	4
scattered pine + hardwood	yes	no	5
scattered hardwood	yes	no	6
dense pine	yes	yes	7
dense pine + hardwood	yes	yes	8
dense hardwood	yes	yes	9

- **Sources** of information for the database (Appendix 1)
- **Species** used in the database and the **common names** that have been used in Itasca, with a preferred common name selected (Appendix 2, currently only trees and shrubs are entered, but other plant and animal species can be added)

I.C. Results: Summary of pine management history

In this section I present a text summary of the management of each supersite stored in the database. Treatment units and a rating of the recent status of pine regeneration are included; these are described and used in Chapter 2. The possible reasons for the recent status of treatment units are discussed in Chapter 2.

The sites are roughly sorted by date and also grouped by manager or project. The grouping by manager may give the illusion that different managers were working at different, rather than concurrent, times. This is really not the case, although during any given period certain managers or projects are more prevalent and better documented than others.

There is a considerable range of confidence in these histories; I have tried to indicate my level of confidence when it is low, but errors in any of the information are still possible.

The format of history summaries is as follows:

Target species are the species recorded as the target by the manager, or inferred from the manager's actions or the existing species on the site.

Treatment units are the sites that are units of analysis used in Chapter 2. Each is represented by its Site ID, followed by its subsite name in parentheses. Full names are shown in Appendix 4 and locations are shown in Appendix 5. As described in Chapter 2, each unit is assigned a *status* rank based on 1995 or 1996 pine abundance and condition, regardless of pine species. This rank is shown after each unit name, represented by the following symbols:

+	status A (promising)
–	status C (unpromising)
x	status B (medium status)

If not all target species are currently present on the unit, the species which are present are listed.

Overstory is a description of the pre-management tree canopy, and, if different, the pre-propagation tree canopy.

Treatment summary is a summary of treatments done to the site. See "Treatment Definitions" above for descriptions of the terms used.

Notes about recent regeneration conditions (or other topics) are included if there is useful information beyond the status rank. Pine regeneration densities and other details relevant to analysis are given in Chapter 2.

The following species are represented by 2-letter codes in the text:

JP	jack pine (*Pinus banksiana*)
RP	red pine (*Pinus resinosa*)
WP	white pine (*Pinus strobus*)
WS	white spruce (*Picea glauca*)

The scientific names of other species are given in Appendix 2.

Pictorial representations of these histories, using Level 2 treatment types (Table 2), are shown after the histories in Figure 3. While monitoring activities are shown in the timelines, they are usually not mentioned in the histories.

I.C.1. Pre -CCC Sites ("Early Plantings"), 1915-1925

Very little is known about these sites; the only information is from Thoma (1994; the title itself is of interest: "Early tree planting in Itasca State Park...a.k.a....a very expensive way to feed deer"). The site names are based on the general location of the planting. The work was done by University of Minnesota Forestry School and possibly others. There are no treatment units for these sites due to lack of information. Current conditions are unknown.

<u>Clarke Lake 1-3 (CL1, CL2, CL3)</u>
Target species: WP, RP (Clarke Lake 1 mostly RP; Clarke Lake 2 mostly WP)

Treatment summary: Planted in rows in 1915.

<u>World War I Plantings (WWI)</u>
Target species: ?

Treatment summary: Various plantings in different locations during World War I (around 1918).

<u>Josephine and Deming Lakes (JDL)</u>
Target species: WP, RP

Treatment summary: Planted in 1919.

<u>Hubbard Ravine (HBR)</u>
Target species: RP

Treatment summary: Planted in 1920 and probably 2 or 3 times before.

Campground Planting 1 & 2 (CP1, CP2)
Target species: ?

Treatment summary: Planted in 1921.

LaSalle Spring Trail (LST)
Target species: ?

Treatment summary: Planted in 1921.

Douglas Lodge Planting (DLP)
Target species: RP

Treatment summary: Planted larger trees in 1921.

Chambers Creek (CHC)
Target species: ?

Treatment summary: Planted in 1921.

Mantrap Cabin (MTC)
Target species: ?

Treatment summary: Planted in 1921.

Hays Lake (HYL)
Target species: ?

Treatment summary: Planted in 1922.

Hernando De Soto Lake (HSL)
Target species: JP?

Treatment summary: Various plantings in 1922.

Middlewest Cabin Site (MWC)
Target species: ?

Treatment summary: Planted in 1923, and perhaps also in 1925.

I.C.2. Civilian Conservation Corps (CCC) Sites

The Civilian Conservation Corps (CCC) was active in Itasca during the extent of the government program (1933 - 1942). The men worked on numerous engineering and development projects, suppressed fires, and provided forest management labor (planting, inventory, blister rust control, etc.)' This era is described in Thoma (1984) and Dobie (1959). The information for the CCC Reproduction Plots described here is from Thoma (1988), and the information about Forestry Demonstration Area, which is likely incomplete, is from Hansen (n.d.).

Mary Lake Deer Exclosure (CCC Reproduction Plot #1) (MLE)
Target species: WP

Treatment units/Status: MLEF (fenced) + , MLEU (unfenced) –

Overstory: dense old-growth RP with some JP, WP, birch, and aspen

Treatment summary: In Oct. 1937 subplots were site prepared by grubbing, raking, or disking; subplots within these were seeded to WP immediately afterwards. Some subplots outside the fence were entirely seeded. The deer fence was installed in Nov. of that year; half of it had rabbit fencing, which was effective for about 15 years. Apparently nothing else done besides monitoring, which has been intensive.

Notes: See Steingraber (1989) and Ross *et al.* (1970) for detailed discussion of this site.

CCC Reproduction Plot Number 2 (CC2)
Target species: WP

Treatment units/Status: CC2F (fenced) – , CC2U (unfenced) –

Overstory: dense RP with some JP, with some associated birch, aspen, WP. (CC2U mostly JP.)

Treatment summary: In Oct. 1937, subplots of the fenced area site prepared by raking, grubbing, or disking, and portions in and out of these subplots were seeded with WP. The area outside the fence was disked twice and seeded to WP between diskings. The deer fence was installed the same year, but the exact timing is unclear. The fence was removed 3 - 7 years later (early 1940s) and used for bison pens elsewhere in the Park.

Notes: "Absolutely no evidence of any pine reproduction since the 1930s" (Thoma 1988).

CCC Reproduction Plot Number 3 (CC3)
Target species: WP

Treatment unit/Status: CC3 –

Overstory: aspen - birch (with 2 overstory RPs); a portion marked "Ms" may have been a marsh

Treatment summary: Probably not cut. In Oct. 1937, subplots were site prepared by raking or grubbing, and portions in and out of these subplots were seeded with WP. Another area, labeled "Ms" and apparently wet, was planted with northern cedar. The deer fence was installed the same year, but the exact timing is unclear. There is no record of a control outside the fence. Part of the fence was apparently removed 3 - 7 years later (in the early 1940s) and used for bison pens elsewhere in the Park.

Notes: "Absolutely no evidence of any pine reproduction since the 1930s....No evidence of the 320 white cedars...can be found" (Thoma 1988).

Forestry Demonstration Area (FDA)
Target species: RP, JP?, WS, Scotch pine

Treatment unit/Status: FDAM (monitored) +

Overstory: probably clearcut

Treatment summary: Probably cut. Planted RP in spring 1937, presumably on 18 acres. Supplemented a 15-acre portion with more RP in spring 1939 and a 7-acre area with WS in fall 1940. A deer fence was installed (again, apparently 18 acres), but the timing in relation to the plantings is not known. At some time Scotch pine was planted in one portion. In 1970 (33 years later) Henry Hansen thinned about one acre.

Notes: The thinned acre and adjacent control area (about 3 acres) together are the treatment unit FDAM, the only area in which Hansen (n.d.) estimated pine density and the only area with a high pine density. The source and reliability of Hansen's (n.d.) information is not known; in particular it is unclear if FDAM was treated differently than other portions of the site (prior to 1970). The entire site is now a demonstration area for tourists.

I.C.3. Early Henry Hansen Sites (Demonstration Spray Sites and EPE)

At the Demonstration Spray Sites, Henry Hansen tested "the use of chemical sprays to control upland brush as a stimulus to the natural regeneration of pine" (Hansen 1952). All sprayings were done under a canopy, and no other treatments were applied. East Park Entrance is not part of this project, but is included here because it is a Henry Hansen project that occurred at about the same time.

East Park Entrance (EPE)
Target species: RP, JP

Treatment unit/Status: EPE +

Overstory: unknown, probably "sparsely vegetated" after the fire

Treatment summary: It appears that Henry Hansen (?) took advantage of a small wildfire that occurred in 1946. It appears that he planted RP and JP after the fire, although I have not found a record of this or any other potential treatments. In 1970 (24 years later) Henry Hansen removed overtopping aspen and a few RP.

Demonstration Spray Number 1 (DS1)
Target species: WP, RP, JP

Treatment units: none

Overstory: a small opening in a pine stand, presumably natural

Treatment summary: Sprayed understory brush with Dow Esterone (a 50-50 mixture of 2,4-D and 2,4,5-T) in August 1952, at twice as heavy a concentration as was usual. There were 4,000 pine seedlings/acre (aged 4-8 years) at the time of spraying; they were probably natural.

<u>Demonstration Spray Number 2 (DS2)</u>
Target species: any pine

Treatment units/Status: DS21 (along the road) –, DS22 (1-acre plot) –

Overstory: old growth RP with birch-aspen understory (?)

Treatment summary: Sprayed understory brush with 2,4-D in August 1952. There was no existing pine reproduction.

Notes: In 1996 there was no visible difference in regeneration between the sprayed areas and adjacent untreated areas.

<u>Demonstration Spray Number 3 (DS3)</u>
Target species: any pine

Treatment unit/Status: DS3 –

Overstory: birch - aspen - a little pine

Treatment summary: Sprayed understory brush with Dow Esterone (a 50-50 mixture of 2,4-D and 2,4,5-T) in August 1952. There was almost no existing pine reproduction.

Notes: In 1996 there was no visible difference in regeneration between the sprayed areas and adjacent untreated areas.

I.C.4. Henry Hansen's "Ecology and Management of Forest Recreational Areas"

These projects are the "Vegetation Management Research" portion of the Hansen *et al.* (1974) Technical Bulletin, "The Ecology of Upland Forest Communities and Implications for Management in Itasca State Park, Minnesota." (Old Park Entrance was part of this project but was not written up in the Bulletin.) However the best information came from "The Ecology and Management of Forest Recreational Areas" progress reports. There is no H. Hansen documentation of these sites after 1974; it appears that they were taken over by the Department of Natural Resources.

The purpose of the overall project as given in the 1974 publication is "to study the ecological consequences of past use and protectionistic management on Minnesota's oldest park." They conducted "pilot scale trials of various management practices—such as burning, logging, use of herbicides, seeding, and planting. . . centered on measures to regenerate pine under existing over-mature stands and to convert some aspen stands back to their prewhite man [sic] composition," (Hansen *et al.* 1974).

Lake Alice Trail (1956 Aspen Conversion Area) (LAT)
Target species: RP, JP, WS

Treatment unit/Status: LAT + (RP only)

Overstory: clearcut of aspen

Treatment summary: Sprayed with 2,4-D - 2-,4,5-T in August 1956, then removed aspen the same month. The stumps were sprayed with 2,4-D soon after felling. Planted RP, JP, and WS the next spring (1957). A year and a half later (Aug. 1958) sprayed 2,4-D in the east third and 2,4,5-TP in the west two-thirds. Sprayed again 11 years later (Sept. 1969) with 2,4-D - 2,4,5-T, and the next year cut out remaining live aspen saplings (1970). (I think all spraying was aerial.)

Squaw Lake East (SLE)
Target species: RP, JP, WP

Treatment units/Status: SLEE (east) – , SLEN (1975 burn control) – , SLEW (bladed) – , SLER (remainder) –

Overstory: aspen - birch - oak, cut leaving scattered hardwoods

Treatment summary: This site started out as two separate projects, but was later combined into one new project which obscured the work done to the first 2 projects. (It therefore holds the record for the site with the most names!)

1. "Squaw Lake East Experimental" (SLEW and a small part of SLER): In Aug. 1967 sprayed subplots with 2,4-D, then removed aspen and oak from a portion (SLEW) which included half of the sprayed plots. In May 1969 seeded some subplots (in seed spots) with RP and planted others with RP or WS. An unseeded and unplanted portion of the felled area was sprayed with 2,4-D in Aug. 1970 and planted RP and JP in 1972.

2. "Squaw Lake East I" (SLEE): In Feb. 1972 removed all trees (aspen, birch, oak) from southern portion and left patches of these hardwoods in northern portion. Mechanically rolled immediately afterwards and planted RP, JP, and WS that spring. Released with 2,4-D that August.

3. Squaw Lake East II (SLE): This burn project, which apparently was done on top of the previous treatments (considered failures), was just a plan in the 1974 publication. However the aspen and birch had already been removed from the rest of the site (SLER and probably SLEN, in the winter of 1972-73) in preparation for burning. In July 1975, knocked down the aspen

sprouts in felled portion of "Squaw Lake Experimental" (SLEW) using a bulldozer with the blade raised about 1 foot off the ground. That Oct. burned the entire site (SLER), except for a small control area (SLEN). Burned again 3 years later (Nov. 1978, apparently including SLEN) and seeded RP afterwards. Planted with all 3 pines at least twice, probably 1982, 1985, and a portion (SLEE) in 1986.

Notes: In 1995 I found absolutely no pine regeneration, even in the occasional grassy clearings.

<u>Henry Hansen Northeast (HNE)</u>
Target species: RP, WS

Treatment unit/Status: HNE +

Overstory: clearcut of aspen - birch - oak

Treatment summary: Sprayed with Weedone (2,4-D; 2,4-DP; 2,4,5-T; 2,4,5-TP; or a combination) in July 1967, and removed all "merchantable timber" (mostly aspen) a year later (winter 1968-69). Sprayed again the next fall (Sept. 1969, with 2,4-D - 2,4,5-T (aerial)), followed by mechanical rolling. Planted RP and WS the next spring (1970) and in spring 1971, 72, and 74. Applied more herbicide (2,4-D) in Aug. 1972.

<u>Henry Hansen Southeast (HSE)</u>
Target species: RP, WS

Treatment unit/Status: HSE +

Overstory: clearcut of birch - aspen

Treatment summary: Sprayed with Weedone (2,4-D; 2,4-DP; 2,4,5-T; 2,4,5-TP; or a combination) in July 1967, and removed all "merchantable timber" (aspen and birch) a year later (1968-69, some felling was done in the summer). Sprayed again the next fall (Sept. 1969, with 2,4-D - 2,4,5-T (aerial)), followed by mechanical rolling. Planted RP and WS the next spring (1970) and in spring 1971 and 72). Removed brush (mostly aspen) in Jan. 1979, nine years after first planting.

<u>Old Park Entrance (OPE)</u>
Target species: any pines (?)

Treatment units/Status: OPE –

Overstory: dense RP - WP - hardwoods

Treatment summary: Sprayed understory brush with Weedone (2,4-D; 2,4-DP; 2,4,5-T; 2,4,5-TP; or a combination) in subplots in July 1967. No existing pine regeneration is mentioned.

Notes: These treatments were probably the beginning of a larger project which was abandoned.

Sewage Lagoon East (LGE)
Target species: RP, WS

Treatment units/Status: LGEF (fenced) + , LGEU (unfenced) –

Overstory: aspen - hardwoods - WP - RP - JP, cut leaving scattered WP, RP

Treatment summary: Aspen and birch were removed in winter 1969-70, leaving scattered RP and WP. Mechanically rolled just after felling. Planted RP and WS that spring (1970), and released a small portion (including part of fenced area) with 2,4-D in Aug. 1970 (not aerial). The 1.8 acre exclosure was installed that year. The following fall (1971), the entire site was sprayed with 2,4-D and planted with WS. The next spring (1972) the site was fully replanted (1970 planting had failed) with RP, JP, and WS, and in late summer the whole site was sprayed with 2,4-D. Planted more RP and some white cedar the next spring (1973), and sprayed again with 2,4-D (by helicopter) that August. Fully replanted with RP the next spring (1974).

Sewage Lagoon West (LGW)
Target species: RP, WP

Treatment units/Status: LGWM (seeded) – , LGWS (unseeded) –

Overstory: RP - WP / aspen - birch - hardwoods, cut leaving scattered and grouped pine

Treatment summary: Removed aspen and birch in March 1971, leaving RP and WP (scattered and in groups). Burned the following spring (1972), and seeded an area with RP and WP to supplement natural seeding. In spring 1973 no pine seedlings were found in monitored plots, however a bumper crop of WP seeds was observed, and a fall burn was planned. Applied 2,4-D (aerial) in Aug. 1973 to increase fuel for burn, but weather conditions that fall were unfavorable for burning so disked instead (fall 1973). The next July (1974) 50,000 WP seedlings per acre were found, but these apparently quickly disappeared.

Notes: In 1995 I found absolutely no pine regeneration.

Old Bemidji Road Area (OBR)
Target species: RP, JP

Treatment units/Status: OBRC (clearcut area) + (RP only) (*Another subsite (OBRR, old road) was excluded from analysis due to lack of information.)*

Overstory: OBRC was clearcut of JP; OBRR was old road.

Treatment summary: In OBRC, cut JP and aspen in Feb. 1971, mechanically rolled and burned the slash in March & April; then planted RP that April-May. The old road (OBRR) was planted at the same time. Planted both subsites with RP and JP the next spring (1972), and again with just RP 2 years later (1974). Removed brush from OBRC in Jan. 1979 (5 years later).

Notes: In 1979 there were 300 RP/acre on OBRC; there has been a lot of mortality since, but there was still a good stand of RP (no JP) in 1996. At some point the old road was converted back into a real road used by Park Managers; the condition of the subsite at that time is unknown.

Two-Spot Trail Burn (TST)
Target species: JP, plus RP in seeded area

Treatment units/Status: TSTD (seeded) – , TSTM (main) –

Overstory: dense JP with WP and RP in east and birch - aspen - hardwoods in west

Treatment summary: Apparently did not cut the site. A summer 1970 burn was attempted but did not get going. Successfully burned in May 1971, and seeded RP in small plots (TSTD). The JP seed trees did not produce much. Possibly burned again and seeded (entire site?) 3 years later (1974).

Squaw Lake West (SLW)
Target species: RP, JP

Treatment units/Status: SLWW (west) – , SLW1 – , SLWS (south) – , SLWM (main) –

Overstory: aspen - birch - JP, cut leaving scattered and grouped pine and grouped hardwoods

Treatment summary: In Mar. 1974 cut most aspen and birch and some JP, leaving 2 small pine stands and some hardwoods. (Entire portions of hardwood areas were left uncut because of a poor timber market.) Burned a small portion (SLWW) that fall (Sept. 1974), and whole site the next spring (May 1975). Seeded with RP and JP that spring (presumably after the burn although the recorded dates contradict that). The next year (1976) planted RP (?) in a portion (SLWS) and seeded a portion (probably SLW1 and SLWS). Reburned the entire site (or at least most of it) 2 years later (Nov. 1978). (There was a plan to burn again in 1980, but there is no indication it was carried out.) Some portions (SLW1, SLWS) were seeded in fall 1981 and planted with RP in spring 82. A portion (SLW1) was mechanically scalped, probably in 1983, and the furrows were planted with RP and some WP, probably in 1984.

Notes: See Patterson (1978) for a detailed discussion of this site.

I.C.5. Minnesota Dept. of Natural Resources Forestry, Parks, etc., 1974-1991

Headwaters Parking Lot (HPL)
Target species: RP, others?

Treatment unit/Status: HPL +

Overstory: clearcut of JP, but by the time propagation occurred, it was an old field

Treatment summary: Cut JP in 1954 and relied on natural seeding. By the time it was planted 18 years later (1972), in was considered an old field; I don't know if additional treatments caused this "conversion." The 1972 planting was at least RP, based on current conditions. The site was planted again after 14 years (1986) and perhaps additional times. In addition to RP, WS appears to have been included in this planting.

Notes: Some pines were removed for transplants and by a wildfire in 1976.

<u>Red Pine 6 (RP6)</u>

Target species: RP?

Treatment units: none

Overstory: ?

Treatment summary: Paul Rundell found the plantation but knows nothing about it; he says it looks like it was planted around 1966-1970. The trees are in rows.

<u>Park Drive 1 (PD1)</u>

Target species: WP

Treatment units: none

Overstory: dense mixed

Treatment summary: Cut brush in spots, wherever they saw natural WP, in 1975-6 and 1988.

Notes: In a 1990 survey, there were 780 white pine/acre, but 85% were browsed.

<u>Park Drive 2 (PD2)</u>

Target species: WP

Treatment units: none

Overstory: dense mixed

Treatment summary: Cut brush in 1974, 1976, and 1987, to stimulate WP reproduction.

Notes: According to P. Rundell, "WP regenerated."

<u>Park Drive Peace Pipe (PDP)</u>

Target species: WP

Treatment units: none

Overstory: dense mixed

Treatment summary: Cut brush in discontinuous strips in 1974, 1976, and 1987, probably to stimulate WP reproduction, and perhaps also to release existing WP.

Notes: According to P. Rundell, "WP regenerated naturally," and there were 3 strips of WP visible, dating to the 3 treatments. In 1995 I could not find them, nor could I find any regeneration <20 years old, I think because the treated areas were indistinguishable from untreated areas.

Big Pine 1 (BP1)

Target species: RP, JP, WP, WS

Treatment units/Status: BP1H (burned/herbicided) – , BP1Y (cut only) –

Overstory: aspen - pines - hardwoods, cut leaving scattered pines and non-aspen/birch hardwoods

Treatment summary: From 1976-81 cut aspen and birch (except where too wet) in several logging operations, leaving other hardwoods and pines. In fall 1979 a subsite (BP1H, which was presumably cut by then) was sprayed; this subsite was burned twice, probably that same fall (1979) and the next year (1980). After the second burn the subsite was seeded with (mostly) JP, and 2 portions were planted with (mostly) RP. Started over in 1984: furrowed both the burned (BP1H) and unburned (BP1Y) subsites with a nose plow wherever they could, and seeded with (mostly) JP. In 1985 and 1986 planted (mostly) RP in the furrows. Also cut another subsite (BP1W), but nothing else was done there.

Notes: According to P. Rundell, the herbicide killed 95% of the aspen, the first burn was "spotty," and the second burn was a "very good burn." In 1995 I found no regenerataion except some WS.

Big Pine 2 (BP2)

Target species: no real target species, because after cutting the project was abandoned

Treatment unit/Status: BP2 –

Overstory: aspen - oak - other hardwoods, cut leaving non-aspen/birch hardwoods

Treatment summary: From 1980-84 cut aspen and birch in several logging operations, leaving other hardwoods.

Notes: According to P. Rundell (1994 pers. comm.), there is no regeneration.

Big Pine 3 (BP3)

Target species: RP

Treatment units/Status: BP3D (furrowed) – , BP3U (wet) –

Overstory: aspen - pines - hardwoods, cut leaving scattered hardwoods

Treatment summary: In the winter of 1983-84, cut aspen (& birch?), leaving other hardwoods. In 1984, furrowed the drier portions (BP3D) with a nose plow. Planted RP with some WP and JP in any unflooded furrows in 1986.

Red Pine 7 (RP7)
Target species: WP, RP

Treatment units: none

Overstory: old beaver area (beaver had cut out most of the trees)

Treatment summary: In 1979 found spotty natural regeneration in old beaver area. Planted WP and RP in 1981.

Notes: According to P. Rundell (1995 pers. comm.), this site "ended up being part of a deer yard."

Red Pine 8 (RP8)
Target species: pine, WS

Treatment units: none

Overstory: old road

Treatment summary: Planted "mixed" pine (probably all 3 species) and WS in 1984, to screen view of parking lot from lake.

Red Pine 9 (RP9)
Target species: JP, WS

Treatment units: none

Overstory: sedges and bare ground

Treatment summary: Planted JP, WS, and some RP in 1982 (with no site preparation).

Notes: According to P. Rundell (notes from circa 1990), only WS is left.

South Boundary Homesite (SBH)
Target species: RP, WP

Treatment units: none

Overstory: old field/homesite

Treatment summary: Planted RP and WP before the site was acquired by the Park, around 1973-1976. (The trees looked 5-8 years old when Paul Rundell went there in 1981; there had been no site prep; the bare gravel around buildings had even been planted.)

I.C.6. Old fields & roads, 1982

Miller's Field (MIF)
Target species: RP, JP, WP

Treatment units/Status: MIF + (RP only)

Overstory: old field

Treatment summary: Planted "mixed" pine (probably all species) into an old field in 1982. The next year (1983) planted again where seedlings had been killed by pocket gophers, flooding, and party-goers. Probably planted again the next year (1984). Two years later (1986), planted more RP.

Miller's Old Road (MIR)
Target species: RP, JP, WP?

Treatment unit/Status: MIR x

Overstory: old road

Treatment summary: Planted an old road in 1982 (unknown species) and seeded with JP in 1984 (2 years later).

Sawmill Field (SMF)
Target species: RP, WP?, WS

Treatment unit/Status: SMF + (RP)

Overstory: old field

Treatment summary: Planted "mixed conifers" into old field in spring 1982. The next year started over due to low survival: mechanically scalped with a Leno scarifier in 1983 and planted RP and WS in spring 1984.

Notes: According to a 1986 survey (P. Rundell notes from circa 1990), only WS survived the second planting. However, in 1996 there was a good density of RP and no WS in the south half, and no RP but WS in the north half.

Old Mary Lake Road (MLR)
Target species: RP, WP, JP?, WS, balsam fir

Treatment units: none

Overstory: old road

Treatment summary: In 1982 seeded an old road with a pine and spruce mixture and planted RP. Seeded with WS and balsam fir 2 years later (1984), and planted (unknown species) in 1985.

Trading Post Field (TPF)
Target species: RP, WP?, WS

Treatment units/Status: TPFE (tent campground) – , TPFW (old field) x (RP)

Overstory: old tent campground with scattered and grouped hardwoods (TPFE), and old field (TPFW, farmed by Wigman and later kept mowed as the trailer part of the campground)

Treatment summary: Planted old tent campground with WS and perhaps other species in 1982. This portion was probably not site prepared. The old field (TPFW) was mechanically scalped with a Leno scarifier, probably in 1982, before planting (RP?) in 1983.

Notes: In 1996 there was WS in both subsites and RP only in the old field (TPFW). Both RP and WS were highly clumped.

I.C.7. "Priority Sites"

In 1986 the "Techniques Subcommittee" (Ron Kuchel, Jon Ross, and Paul Rundell) selected these sites and recommended treatments. All but Centennial Forest had been previously managed for pine. All were fenced at about the same time, and for most, this was the last treatment done as of 1994. Jack Pine Restoration #2 is not one of these sites, but is included here because it was initially part of Jack Pine Demonstration Area.

<u>Lagoon Burn Area (LBA)</u>
Target species: RP, WP

Treatment units/Status: LBAF (fenced) – , LBAC (control) –

Overstory: pine - spruce - fir - aspen, cut leaving dense pine

Treatment summary: In 1975 cut out balsam fir, aspen, and spruce, leaving pine overstory. Burned fall of 1975. Burned 4 years later (fall 1979) and again in spring 1981. Seeded to RP and WP after the 1981 burn. Removed brush in 1987 or 1988 (6-7 years later) and installed exclosure in 1988 or 1989. Planned to burn again but never got the proper conditions, and then decided there was enough WP regeneration. Instead removed brush in 1990 and seeded to WP afterwards.

Notes: In 1996 the WP regeneration density was high outside the fence but almost all of it was 1 year old or less. There was almost no regeneration inside the fence.

<u>White Pine Knob (WPK)</u>
Target species: WP, RP

Treatment units/Status: WPKF (fenced) – , WPKC (control) –

Overstory: pine - aspen - birch - oak, cut leaving scattered pine

Treatment summary: Removed hardwoods (mostly aspen and birch) in the winter of 1979-80, leaving scattered pine. Burned in 1980 (spring?) and again the next year. Seeded with RP and WP after the second burn. Never got conditions to burn again, but maintained the firebreak. Installed deer exclosure about 9 years later (about 1988).

Jack Pine 1 (JP1)

Target species: RP, JP

Treatment units/Status: JP1Y (fence/burn/spray) +, JP1M (fence/burn) +, JP1N (fence) + (JP only), JP1U (unfenced) –

Overstory: JP - aspen - some RP, cut leaving scattered RP (mostly in southwest), some JP, and a couple spots of aspen; JP1N and JP1U had essentially no overstory remaining

Treatment summary: Cut just about all trees (mostly JP) in spring 1980, leaving all RP, some JP, and aspen in 2 spots. Piled the JP slash in one area (JP1N). In March 1981 burned most of the site (JP1Y, JP1M, JP1U), and seeded the burned area heavily with JP and RP. The next spring (1982), planted the whole site with RP and JP. Because the seeds were consumed by rodents and the seedlings eaten by deer, replaced 2 years later (1984) with more seedlings and seeds. Then, probably in 1985, removed hazel from the entire site. Planted again in 1987, and spot-treated with Roundup in most of the burned area (JP1Y, JP1U). That winter (1987-88), cut 3 nearby aspen stands in an attempt to attract deer away from the site. Installed the deer fence in 1988. Planted (to fill in gaps) in 1992 and 1994. (The 1992 planting was not done outside the fence (JP1U)).

Notes: The aspen cut (deer lure) was said by P. Rundell (1995 pers. comm.) to be ineffective at reducing deer damage.

East Contact Station (ECS)

Target species: JP, RP

Treatment units/Status: ECSE (fence/spray) + (JP), ECSW (fence) + (JP), ECSU (unfenced) –

Overstory: RP - JP - WP - birch, cut leaving scattered WP and RP

Treatment summary: Cut JP and birch in Dec. 1981, leaving WP and RP. Left piles of brush in an attempt to keep in predators to reduce small mammals. Seeded and planted JP & RP in spring 1982 to compensate for deer damage to natural regeneration. Planted and seeded again in 1984 (2 years later), and planted the south half (of ECSE and ECSW, there was natural regeneration of white pine in the north half) in spring 1986. In Sept. 1987, spot-treated brush in east half (ECSE) with Roundup. Planted the south half again in 1988, and installed the fence that year.

Notes: P. Rundell (1995 pers. comm.) says that the brush piles did not reduce small mammals. Within the fenced area there is an area of exceptionally dense, tall, healthy pines, but it does not appear to be related to any treatment differences.

Jack Pine Demonstration Area (JPD)
Target species: JP, RP

Treatment units/Status: JPDF (fenced) + (esp. natural WP), JPDC (control) x

Overstory: JP - RP - hardwoods (?), cut leaving scattered RP

Treatment summary: Cut all trees (mostly JP) in winter 1981-82, leaving scattered RP. That spring (1982), to supplement natural seeding, seeded with JP and RP and planted JP, RP, and WS. Reseeded the next fall (1983), and planted the next spring (1984). In summer 1988 cut out brush twice and installed the deer fence. Cut out brush again (JPDF only?) in 1990 and 1992, and planted, in the fence only, in 1994.

Jack Pine Restoration #2 (JR2)
Target species: JP, RP

Treatment unit/Status: JR2 –

Overstory: JP - RP - hardwoods, cut leaving scattered RP

Treatment summary: This site apparently received the same treatments as JPD through 1982.

Centennial Forest (CFO)
Target species: JP, RP, WP?, WS

Treatment units/Status: CFOF (fenced) x (JP), CFOC (control) –

Overstory: probably same as ECS, cut leaving scattered WP and RP

Treatment summary: Cut in fall 1990, leaving scattered pines. That winter site prepared by shearing, and in May (1991) planted JP, RP, and WS and seeded JP. The fence installation was completed by that August (1991).

I.C.8. Old fields & roads, 1994

Red Pine 13 (R13)
Target species: RP, JP

Treatment unit/Status: R13 x

Overstory: old field

Treatment summary: Planted old field with RP and JP in 1994.

Notes: There is a possibility that it was site prepped and planted at earlier times, but the furrows are probably from agriculture and the few existing older JP and RP are likely natural.

Red Pine 4 (RP4)
Target species: RP, JP

Treatment unit/Status: RP4 –

Overstory: old field

Treatment summary: Planted old field with RP and JP in 1994.

Notes: There is a possibility that it was site prepped and planted at earlier times, but the furrows are probably from agriculture and the few existing older JP and RP are likely natural.

<u>Roy Hemrick Homesite (RHH)</u>
Target species: WP, WS

Treatment unit/Status: RHH –

Overstory: old field with scattered trees and shrubs

Treatment summary: Planted old field with WP in 1994. Had planted spruce at some earlier time.

<u>Bert's Cabins Gravel Pit (BCG)</u>
Target species: RP

Treatment units: none

Overstory: old gravel pit

Treatment summary: Planted RP in 1994.

<u>Southeast Gravel Pit (SGP)</u>
Target species: JP

Treatment units: none

Overstory: old gravel pit

Treatment summary: Planted JP and some RP in 1994.

Notes: Most jack pine died immediately after planting, probably because planted too late after lifting and weather too dry for planting on gravel.

<u>North Boundary Homesite (NBH)</u>
Target species: WP

Treatment units: none

Overstory: old homesite with heavy sod

Treatment summary: Planted WP in 1994.

<u>South Entrance Road A & B (SRA, SRB)</u>
Target species: RP

Treatment units: none

Overstory: roadside slumps (mostly bare ground)

Treatment summary: Planted RP in 1994 to reduce erosion on steep slope.

Figure 3. Management History Timelines. Each symbol represents a treatment type, as shown in the legend. Sites are represented by Site IDs; the full site names are given in the history summaries and, for treatment units, in Appendix 4. If the site is a treatment unit, the 1995 status rank (see Chapter 2) is shown by a face in the left-most column, according to the legend. Sites are sorted as in the text: roughly by age and also grouped by project or manager. Sites of the same supersite are grouped together and have the same first 3 letters of their Site ID.

Treatment Legend

✂	Felling
†	Cultural
↗	Mechanical site preparation
≈	Fire
⚡	Wildfire
⌖	Herbicide
⇧	Planting (pine)
❍	Seeding (pine)
□	Exclosure
∇	Brush removal
✓	Monitor

Status Legend

☺	Status A (promising)
😐	Status B (medium status)
☹	Status C (unpromising)

Miscellaneous

?	(after a symbol) question that treatment occurred
~	(after a symbol) timing of treatment is uncertain
⇧	(any symbol with a double strikethrough): the treatment occurred to only a portion of the site

1915-1925: Pre-CCC Sites

	1915	1916	1917	1918	1919	1920	1921	1922	1923
CL1	⇧								
CL2	⇧								
CL3	⇧								
WWI				⇧					
JDL					⇧				
HBR						⇧			
CP1							⇧		
CP2							⇧		
LST							⇧		
DPL							⇧		
CHC							⇧		
MTC							⇧		
HYL								⇧	
HSL								⇧	
MWC									⇧

1936-1945: Civilian Conservation Corp (CCC) Sites

		1937	1938	1939	1940	1941	1942	1943	1944	1945
☺	MLEF	✓↗⊖□								✓
☹	MLEU	✓↗⊖								✓
☹	CC2F	✓↗⊖□					remove□			
☹	CC2U	✓↗⊖								
☹	CC3	↗⊖□					remove□			
☺	FDA	✂⇧□		⇧	⇧					

1946-1960: Early Henry Hansen Sites

		1946	1947	1948	1949	1950	1951	1952	....	**1970**
☺	EPE	⇧?								thinning
	DS1S							⌖		
☹	DS21							⌖		
☹	DS22							⌖		
☹	DS3							⌖		

1966-1979: Henry Hansen's "Ecology & Management of Forest Recreational Areas"

	1956	1957	1958	1960	....	**1969**	1970	1971	1972
☺ LAT	⌖✂⌖	⇧	✓⌖	✓		✓⌖	∇	✓	✓

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	**1982**	1983	1984	1985	1986
☹ SLEW	✓✓	✂~~⌖~~		~~⊖⇧~~✓	✓~~⌖~~	✓	~~⇧~~			blading ≋			≋○				⇧			⇧	
☹ SLER	~~✓✓~~	~~⌖~~		~~⊖⇧✓~~	~~✓~~	~~✓~~		✂		≋			≋○				⇧			⇧	
☹ SLEE				✓		✓	✂↗⇧⌖	✓	✓	≋			≋○				⇧			⇧	⇧
☹ SLEN								✂?					≋?○				⇧			⇧	
☺ HNE	✓✓	⌖		✂⌖↗	⇧	✓⇧✓	✓⇧⌖	✓	✓⇧												
☺ HSE	✓✓	⌖		✂⌖↗	⇧	✓⇧✓	⇧✓	✓	✓					∇							
☹ OPE	✓✓	⌖																			
☺ LGEF					✂↗⇧~~⌖~~ □	⌖✓✓	⇧⌖✓	⇧⌖✓	⇧✓												
☹ LGEU					✂↗⇧~~⌖~~	⌖✓✓	⇧⌖✓	⇧⌖✓	⇧✓												
☹ LGWM				✓		✂	≋✓○	↗✓⌖	✓												
☹ LGWS				✓		✂	≋✓	↗✓⌖	✓												
☺ OBRC						✂↗⇧	⇧	✓	⇧✓					✓∇							
OBRR	† (unknown earlier date)					⇧	⇧		⇧					✓							
☹ TSTD				✓	✓	≋○✓			≋?○?												
☹ TSTM				✓	✓	≋✓			≋?○?												
☹ SLWM								✓✓	✓✂	✓≋○			≋								
☹ SLW1								✓✓	✓✂	✓≋○	○?		≋			○	⇧?	↗~	⇧~		
☹ SLWS								✓✓	✓✂	✓≋○	○?⇧	✓	≋			○	~~⇧~~				
☹ SLWW								✓✓	✓✂≋	✓≋○			≋?								

1974-1991: Minnesota Dept. of Natural Resources (DNR) Forestry, Parks, etc.

		1954	1966	1972	1976	1986
☺	HPL	✂		⇧	↯	⇧
	RP6		⇧?			

		1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
	PD1		∇													∇			
	PD2	∇		∇											∇				
	PDP	∇		∇											∇				
☹	BP1Y			✂	✂	✂	✂	✂	✂			↗○	⇧	⇧			✓		
☹	BP1H			✂	✂	✂	✂⌖≈	≈○⇧	⇧			↗○	⇧	⇧			✓		
	BP1W											✂							
☹	BP2							✂	✂	✂	✂	✂							
☹	BP3D											✂✓↗		⇧					
☹	BP3U											✂✓							
	RP7								⇧										
	RP8											⇧							
	RP9									⇧									
	SBH	⇧~																	

1982: Old Fields and roads

		unknown earlier date	1982	1983	1984	1985	1986	1987	1988	1989	1990
☺	MIF	⧫	⇧	⇧	⇧?		⇧	✓			
😐	MIR	⧫	⇧		○						
☺	SMF	⧫	⇧	↗	⇧		✓			✓	✓
	MLR	⧫	○⇧			⇧					
☹	TPFE	⧫	↗?⇧?		✓	✓			✓		
😐	TPFW	⧫	↗	⇧	✓	✓			✓		

1980-1994: Priority sites

	1975	...	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1994
☹ LBAF	✂≋		≋		≋○					✓		∇~ □		∇○✓	✓		
☹ LBAC	✂≋		≋		≋○					✓		∇~		∇○✓	✓		
☹ WPKC				✂≋	≋○					✓						✓	
☹ WPKF				✂≋	≋○					✓		□~				✓	
☺ JP1Y				✓✂	✓✓≋	✓⇧	✓	✓⇧○	✓∇~	✓✓	⇧✓⊕	✓□	✓		✓	✓⇧	⇧
☺ JP1M				✓✂	✓✓≋	✓⇧	✓	✓⇧○	✓∇~	✓✓	⇧✓	✓□	✓		✓	✓⇧	⇧
☺ JP1N				✓✂	✓✓	✓⇧	✓	✓⇧○	✓∇~	✓✓	⇧✓	✓□	✓		✓	✓⇧	⇧
☹ JP1U				✓✂	✓✓≋	✓⇧	✓	✓⇧○	✓∇~	✓✓	⇧✓⊕	✓	✓		✓	✓	⇧
JP1O												✂					
☺ ECSE					✂	○⇧		○~⇧	✓	✓⇞	✓⊕	✓⇞□	✓		✓		
☺ ECSW					✂	○⇧		○~⇧	✓	✓⇞	✓	✓⇞□	✓		✓		
☺ ECSU					✂	○⇧		○~⇧	✓	✓	✓	✓	✓		✓		
😐 JPDC						✂○⇧✓	✓○	✓⇧	✓	✓✓	✓	∇∇	✓	✓	✓	∇	
☺ JPDF						✂○⇧✓	✓○	✓⇧	✓	✓✓	✓	∇∇□	✓	✓∇	✓	∇	⇧
☹ JR2						✂○⇧✓											
☹ CFOC														✂	↗○⇧		
😐 CFOF														✂	↗○⇧□		

1994: Old Fields and roads

	unknown earlier date	1994
😐 R13	⧫	⇧
☹ RP4	⧫	⇧
☹ RHH	⧫ ⇧?	⇧
BCG	⧫	⇧
SGP	⧫	⇧
NBH	⧫ (1984?)	⇧
SRA	(roadside slump)	⇧
SRB	(roadside slump)	⇧

II. Chapter 2: Analysis of Management History

II.A. Introduction

In this Chapter I use the database described in Chapter 1 to analyze the recent status of pine restoration in the Park.

I first describe the data types used in the analysis. The subjects for the analysis are *treatment units,* the response is the *status* of pine regeneration on the units, and the factors are the *treatments* and *stages* that occurred to these units and the pre-propagation condition of the *overstory*. Each are defined in the first 3 sections. In the next section I describe my field methods and analysis methods.

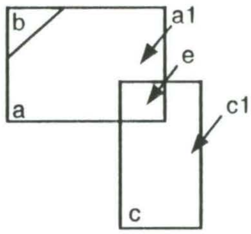
In the results section I first present the density and status results for each unit, and describe the rate of density change for selected units. I then compare the density of the units to values taken from natural stands by Kurmis (1969). Next I summarize the overall treatment history in terms of how often the treatment types (and treatment pairs) have been applied to the population of units. I then look at the relationship of status to treatment applications, first one factor at a time, and then by classifying units by groups of factors.

The next section is a combined discussion and result: brief description of the treatments applied to each unit, discussion of possible reasons for recent pine regeneration status, and comparisons of units with similar treatment schemes.

II.B. Subject: Treatment Units

The sites in the management database (Chapter 1) are all sites for which I could find any management information. The subset of these sites selected for analysis are called "**treatment units**" (or "**units**").

A *site* is defined for an exact land area to which one or more treatments were applied. Therefore sites can spatially overlap and can be defined for rather trivial activities. (See Chapter 1 for a more thorough discussion of sites.) However *treatment units*, in order to be analyzed, cannot overlap. New sites were created to deal with site intersections. In the example of Figure 4, 2 intersecting subsites are shown; one was defined for an herbicide application (**c** = "Jack Pine 1–Herbicide") and the other for a deer exclosure (**a** = "Jack Pine 1–Fenced"). I created 3 new subsites to handle this intersection: "Jack Pine 1–Fence & Herbicide" (**e**), "Jack Pine 1–Fenced only" (**a1**), and "Jack Pine 1–Herbicide only" (**c1**). These 3 subsites are treatment units, while the original 2 subsites and the supersite are not.



Legend

	shape name	unit?
a	Fenced	N
b	Monitor	N
c	Herbicide	N
e	Fenced & Herbicide	Y
a1	Fenced only	Y
c1	Herbicide only	Y

Figure 4. Example of treatment unit selection within a supersite. The diagram shows a "map" of the supersite (Jack Pine 1) and its subsites. Subsites *a* ("Fenced") and *c* ("Herbicide") overlap, and therefore cannot be treatment units. Instead 3 treatment units are used in analysis: *e* ("Fenced & Herbicide"), *a1* (= *a* - *e* = **"Fenced only"), and *c1*** (= *c* - *e* = **"Herbicide only"). Site *b* is not included as a treatment unit because the treatment differences between *b* and *a1* are trivial.**

The criteria for selection of treatment units (*from the set of non-overlapping sites*) were:

1. the activities that separate the site from other subsites within its supersite must be meaningful[2] (In the example in Figure 4, site **b** was defined for a student monitoring study, but was not included as a treatment unit; instead it is simply a part of the "Jack Pine 1–Fenced only" (**a1**) unit which encloses it.),
2. the purpose of the site must have been pine restoration (loosely defined),
3. the record of site treatment history was adequately accurate and complete, and
4. the site could be found in the field for the assessment of recent pine regeneration status.

The selected treatment units are shown in Appendices 4 and 5.

Clearly, treatment units are not randomly selected from the population of treated areas. There is a possible bias towards the selection of sites with more pine regeneration, because these sites are more likely to be carefully documented and known about, and, given the limited time I had to find and survey sites, these sites were a higher priority.

Treatment units are also not statistically independent. Although they do not intersect, treatment units may be adjacent, and they may share many treatment applications in addition to physical and biotic characteristics of the location. In most analyses, treatment units are compared without giving consideration to the dependence of some of the units.

[2] Of 22 sites dropped for this reason, 3 are subsites defined for a monitoring activity, 16 are small CCC subplots, 2 are extra plantings to a small area, and 1 is an extra spraying to a small area.

II.C. Response: "Status"

The purpose of pine restoration work in the Park has been to maintain pine communities by regenerating new communities as the old ones age. The recent status of the restoration units is the response in my analysis. However, rating the status of this or any restoration project is not a simple or well-defined task. The process I used to define and assign status to treatment units is described in this section.

II.C.1. The problem

My first task was to determine how best to measure the status of the units. I looked for recorded goals of the Itasca managers, but these are infrequent, and when present are qualitative and frequently vague. Common purposes given for a site or propagation activity are "reforestation," "site conversion to pine," and "site regeneration."

My impression of the goal of a pine restoration in Itasca State Park is to develop a pine community like the mature pine stands that still exist in the Park. My own ideal is that these units will include all aspects of natural pine communities, not just the pines. However, the concept of "pine community" is rather vague. The Minnesota Natural Heritage program defines 7 pine community types for the Itasca area (Minn. DNR Natural Heritage Program 1993), and the concept for each community type allows considerable variability. By this classification, coniferous forests have more than 80% coniferous tree cover, and mixed coniferous-deciduous forests have 20-80% coniferous tree cover and more than 70% total tree cover. Existing pine communities in Itasca fall into both categories.

Even if one could readily define "pine community," it would also be difficult to measure if a restoration project had achieved such a goal. There are many components one might attempt to measure—such as abundance and condition of the pine trees, vegetation structure, species composition, and ecosystem function—and most are difficult or time-consuming to measure.

Another difficulty is that while the primary interest seems to lie in mature stands, most of the sites are young relative to the maturation time of a pine tree. One must therefore predict whether a site will mature into a recognizable pine community.

Furthermore, the goal itself appears to be unrealistic. The priority for managers has clearly been the establishment of pine trees. Monitoring activities have almost always been focused on pines, rather than the community as a whole; purposes include checking the "survival," "regeneration," "germination," "condition," or "growth" of pines, or on "competition" or "browse" (damage by herbivores). No treatments have been directed towards community development and, if potential effects of treatments on non-pine aspects of the future community have been considered, they have not been recorded. Few sites have developed a tree canopy with a significant pine component that might create an understory environment typical of natural pine forests. The sites that have developed tree-sized pines have low priority for pine restoration; creating this canopy itself has been difficult to achieve.

II.C.2. Definition of status

Based on the above reasons and goals, my concept of status includes only the pine component of the community. My definition is:

Status: the potential for the unit to develop a tree canopy with a substantial component of mature pine trees, based on current pine abundance and condition.

The status variable has 3 levels: high (A), medium (B), and low (C). For ease of writing I sometimes use the terms "promising," "medium status" or "some promise," and "unpromising" to describe these levels (Table 5); it must be kept in mind that I use "promising" and "unpromising" in the relative rather than absolute sense. The relative scale applies to the area of the study and is not a universal measure of all pine stands.

Status is assigned to each unit independent of the treatments applied to the unit, and therefore, an untreated area (such as a control) could be rated as Status A (promising).

Table 5. Levels of Status

Level	Rank	Description
high	A	relatively good chance of mature pine overstory with minimal follow-up; current pine regeneration is relatively **promising**
med.	B	medium or unknown chance of mature pine overstory; requires at least some follow-up; **some promise**
low	C	relatively low chance of mature pine overstory without extensive additional work; **unpromising**

In some analyses I used 2 levels of status, either by removing B (medium-status) units or by combining them with A or C units.

<u>Characterization of pine abundance and condition</u>

I characterize pine abundance using pine density adjusted for age and the spacing of the trees. (A high density value is not as meaningful when the trees are clumped together; most will not survive due to intraspecific competition.)

I characterize pine condition using the height and health of the trees.

Status is based on the combined abundance and condition of all 3 pine species

I estimated the density and assessed the condition of each of the 3 pine species (jack pine, red pine, and white pine) separately, but to assign status I combined the values. My reasons for combining the 3 species are as follows:

1. It is my impression that, given the difficulties in propagating any pine species in the Park, the primary objective of the manager is to grow pines, without too much concern over the species. Managers typically listed "pine," rather than a specific pine species, as the management goal, and they typically have added a mixture of pine species to a site. (Based on available data for 30 supersites, 8 were propagated with only 1 pine species, while 22 were propagated with 2 or 3 pine species.)
2. Even though each of the 3 species of pine is a priority for restoration, the overall goal is to restore pine *communities*. These naturally occur with a mixture of pine species (and other tree species), although often with strong dominance by one species, especially for jack pine.
3. Individual pine species densities in natural pine forests can be very low because they occur as scattered individuals within a matrix of the other pine species. Such an outcome is desirable, even if an individual species was below a density threshold. Furthermore, often the conditions within a subsite are not uniform, and a given species will do well in only a small part of the area. For example, where a canopy shades a portion of the subsite, white pine may survive, whereas jack and red pine are restricted to more open areas.
4. Stocking charts are a useful tool for predicting change in density through time, but these are based on monoculture data. Species growing together cannot individually be expected to reach the "standards" for monocultures, although it is possible for their combined densities to meet or surpass the monoculture densities.
5. The data are limited for studying even combined pine status; to use individual pine status would have compounded the problem.

Even though the value of "status" gives no information about the "status" of a particular species, individual densities are recorded, so the species which most contributed to the existing pine regeneration can be listed. The target species (*i.e.*, species known to be planted) for each subsite can also be listed.

II.C.3. Density criterion

The next step was to determine which density levels should be considered promising or unpromising, given good condition and spacing of the trees. Because of the range of stand ages (3-60 years) in this study, I could not use a simple density cutoff. The density of a pine stand is expected to decrease with the age of the stand both because of cumulative mortality over time and a high mortality of younger trees. Therefore younger stands must be held to higher density standards than older stands.

Ideally I would weigh each tree by its age when calculating density, but the information in the literature and the accuracy of my field data are insufficient. Instead I

1. dropped 1 year-old seedlings from the density results—they have an especially high mortality rate (field observation) and very likely do not contribute information towards predicting future pine abundance—and

2. used the age of the stand as a whole, where

Age of Unit = the modal age of all pines originated after first management of the unit.

To determine realistic density curves to separate the 3 status levels, I looked at the pine density goals of Park managers, the recorded pine density of some natural stands in the Park, the pine densities of some pine plantations in Minnesota and Wisconsin, and the pine density recommendations of the forestry profession. I compared these to the treatment unit densities to ensure that the curves provided realistic goals. This process is described in the next few sections.

II.C.3.a. Pine density goals of Itasca State Park managers

In the recorded goals of Itasca managers, I found no specific target densities or other measurable goals. However, for 17 supersites, species density information is available at different times during the treatment history. Some of these records include the manager's notes on the "desirability" of these densities (and condition of target trees). And for most, the manager's response, in terms of follow-up treatment, is known. In most cases I was able to interpret the combination of comments and action in order to assign the manager's determination of "good" or "inadequate" at that point in time.

My interpretations of the managers comments and actions are shown in Figure 5. There is no clear density cutoff, and the managers' reactions are not closely related to density. The managers used other factors in addition to density—notably competition and tree condition—to make judgments. Their goals may also have changed over time. Therefore, this information was not helpful for determining a density cut-off.

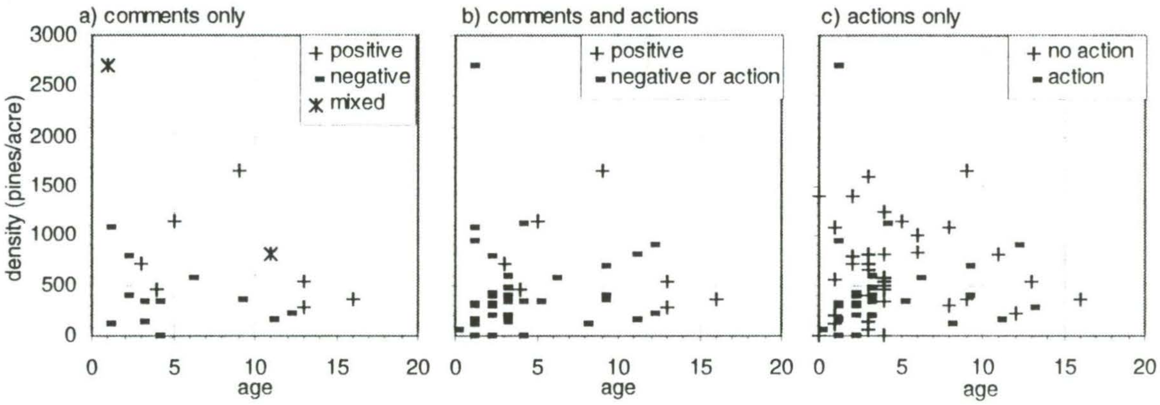


Figure 5. Interpretation of the managers' responses to site monitoring. Each point is a subsite of one of the 17 monitored supersites. Graph (a) shows sites to which the manager made positive or negative comments after monitoring. "Mixed" sites have good results in some areas and poor in others. Graph (b) has the comments shown in (a) plus "negative" marks for subsites on which a follow-up action (such as planting or competition control) was made after monitoring. I considered any follow-up action to be "negative" unless accompanied by a positive comment. Graph (c) shows *all* monitored subsites (except two 3-year-old sites with densities of 4,300 and 50,000 pine/acre and no action) and whether or not follow-up action was taken.

II.C.3.b. Pine density in natural stands at Itasca State Park

Some research has been performed in natural pine stands within Itasca State Park that includes information about pine densities. The stands include a variety of pine community types at different ages (70 to 258 years). None is as young as the stands in this study (the maximum unit age is 60 years), but the stands help to give a better idea of target densities. I chose stands with a dominant pine component, including pine-maple and pine-spruce-fir stands.

I calculated the pine densities for these stands (Figure 6) using raw data included in the sources. Pine density is defined here as the density of all pine trees larger than a certain diameter at breast height (DBH), as selected by the author of the source. The sources for the data are:

- Kurmis (1965, Appendix Table 3) provides the 1965 densities, ages, and diameters for pine trees ≥ 4 inches DBH in his jack pine - red pine, pine - spruce - fir, and red pine forest types. The relative abundance of pine trees in these communities is not specified, except that pine is dominant. He calls them "deteriorating stands."
- Webb (1986) provides densities, ages, and diameters for trees larger than 2.5 cm (0.98 inches) DBH in her pine - maple and pine - fir stands. Red and white pine comprise 66% of the pine - maple stand basal area and 63% of the pine - fire stand basal area.

- The pine overstory density (virtually all RP) of Mary Lake Deer Exclosure is provided for 1937 by Thoma (1988), for 1969 by Ross *et al.* (1970), and for 1984 by Steingraber (1989).[3]

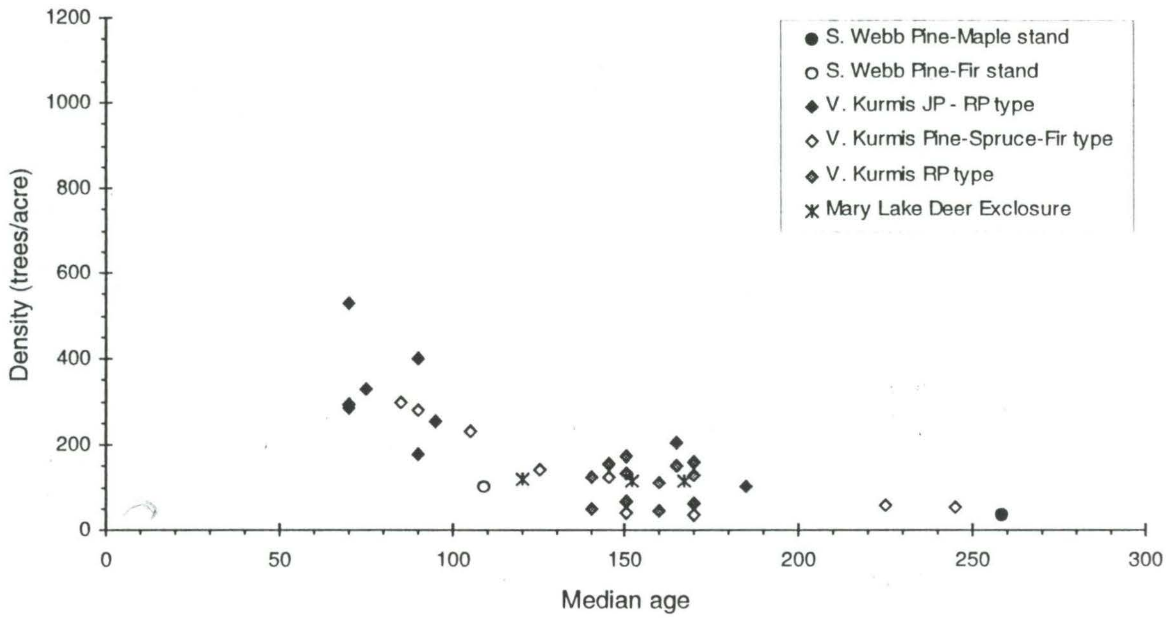


Figure 6. Pine density vs. pine age for natural pine stands in Itasca.

II.C.3.c. Pine density recommendations from the forestry profession

The change in tree abundance through time is a problem of particular interest to foresters managing plantations for commercial production. They have studied the stand abundances needed, during the growth of an even-aged monoculture stand, to attain desired yields by the time of harvest. For restorationists there is no yield or harvest, and natural "rotation" is typically longer than a commercial rotation, but the basic question—"what is the expected decrease in pine abundance over time?"—is the same. While the goals of commercial foresters and pine restorationists are not the same, the information used by foresters can at least be used as general guidelines for restoration, in lieu of any direct restoration studies. Forestry techniques are very commonly used by restorationists, and they have been used heavily in Itasca.

In most cases foresters measure pine abundance using basal area or timber volume, rather than density. However Benzie (1977a, 1977b) provides density versus time information for the north-central states (Minnesota, Wisconsin, Michigan). Time is represented by tree diameter rather than age. The information is for a single species, because the study sites were monoculture plantations.

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[3] Mary Lake Deer Exclosure is also a site in my study, however it is the natural pine stand composing the canopy that is used here, rather than the managed understory.

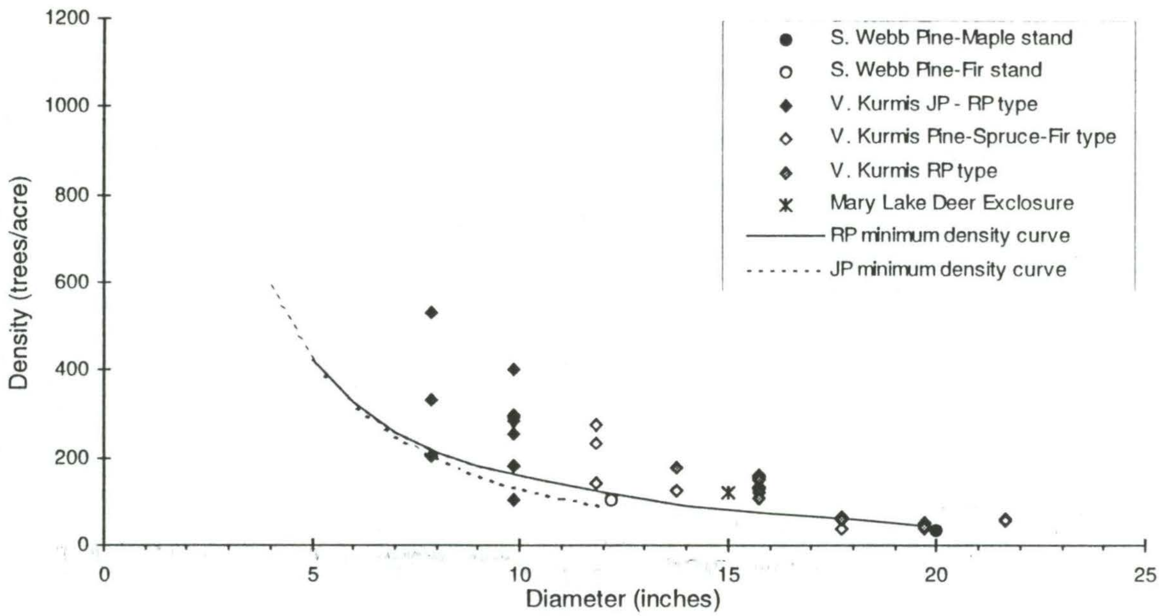

Figure 7. Pine density vs. pine diameter for natural pine stands in Itasca and recommended red pine (Benzie 1977b) and jack pine (Benzie 1977a) minimum stocking curves. The point data are for the same stands as in the previous figure, but density is plotted against diameter instead of age.

The recommended minimum stocking for red pine and jack pine in the north-central states is shown as the 2 lines in Figure 7. For red pine (Benzie 1977b), trees under 5" diameter (seedlings and saplings) should be 400-1,100 trees/acre, at 5" there should be a minimum of 400 trees/acre, and at 9" there should be a minimum of 175 trees/acre. 400 trees/acre is also the minimum recommended planting density. The recommendations for jack pine (Benzie 1977a) are similar: for stands of trees less than 4" in diameter (typically seedlings less than 5 years old) the minimum density is 600 trees/acre, at 5" the minimum is 420 trees/acre, and at 8" the minimum is 200/acre.

II.C.3.d. Minimum density curves

Diameter data are available for the natural stands plotted in the density vs. age graph (Figure 6); these are plotted by diameter in Figure 7 for comparison to the minimum stocking data. The natural pine densities correspond surprisingly well with the foresters' stocking recommendations when plotted against diameter.

Because the natural stands correspond so well with the recommended minimum densities and diameter data are not available for the treatment units, I used the plot of natural stand age vs. density as a guide for rating the treatment units. The underlying assumption is that the relationship of diameter to age is the same for the natural stands as for the managed units.

The comparison of natural stand densities and minimum density curve to treatment unit densities is shown in Figure 8. Ideally this curve would be used to separate promising from unpromising densities. However, only 5 of the 59 treatment units fall above the curve. Such a low count would not be useful for comparisons of promising and unpromising units. Furthermore, many of the units under the curve appear to be promising based on my impression in the field.

Therefore, keeping the same curve shape but lowering it, I drew a more practical minimum density curve. I used my subjective ratings of pine condition, distribution, and abundance to determine how far to lower the curve. Based on these ratings, certain units seemed clearly "promising" to me, while others seemed clearly "unpromising." I used these as a guide, and lowered the curve only enough to get a more reasonable distribution units.

Then, for the age range of this study (3-60 years), I used two straight lines to approximate the minimum density curve. These "buffer" the practical minimum density curve and form 3 sections for each of the 3 status levels. This approximation is shown in Figure 8 and in an enlarged view in Figure 9.

The result of this method is that, while all the units are ranked relative to each other, the status assignments are over-estimates based on the "absolute" scales of selected natural stands and forestry recommendations. In other words, my confidence is not all together high that all the "promising" units will actually become mature pine forests with little to no follow-up. Still, it is useful to know that these units have relatively higher pine survival.

II.C.4. Assigning status

The lines in Figure 8 were used for the initial assignment of status: units below the bottom line were assigned to status C (unpromising), the units between the lines to status B (some promise), and the units above the top line to status A (promising).

I evaluated the initial rank of each unit against the subjective information I took in the field: the spacing, height, and health of the trees, and my observations of pine abundance in the unit as a whole (outside of my sampled area, see field methods). As a result, a few status ratings do not correspond to the quantitative cutoffs; my reasoning for changing the rating of each of these units is given in the results section (p. 64).

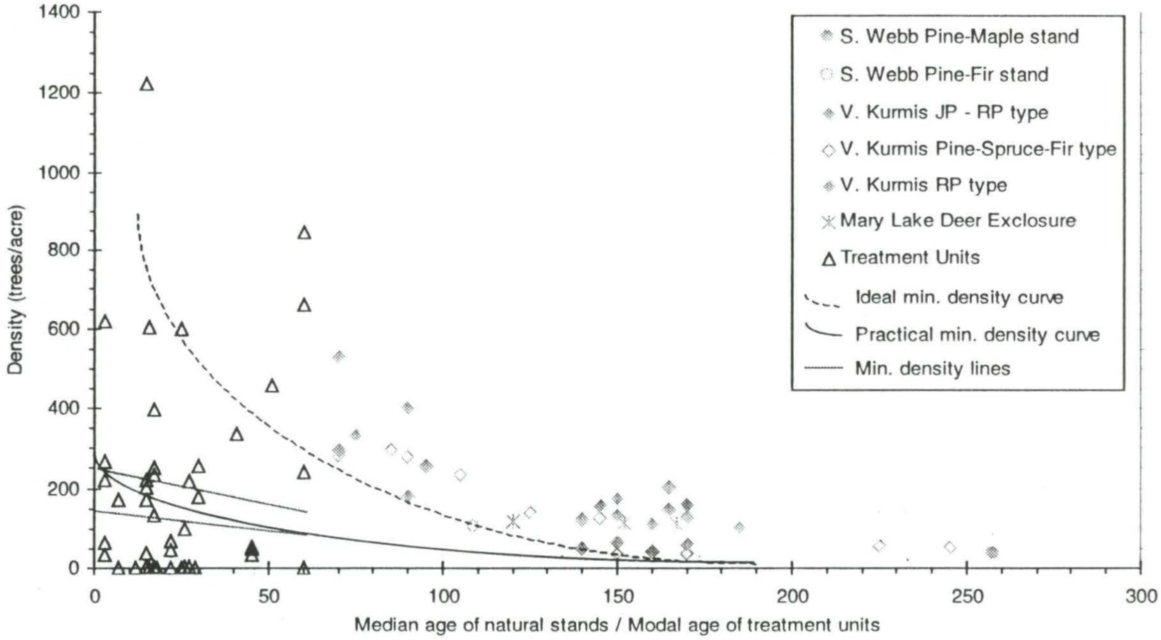

Figure 8. Age vs. density of natural stands (gray) and the treatment units of this study (black triangles), and approximate minimum density curves. The top dashed line is an approximate minimum density curve based on natural stands and stocking recommendations. The lower (solid) curve is a more realistic minimum density curve (based on the distribution of treatment unit densities). The straight lines that approximate the solid curve (with a buffer) are used for the initial assignment of status values to the treatment units (which range in age from 3-60 years).

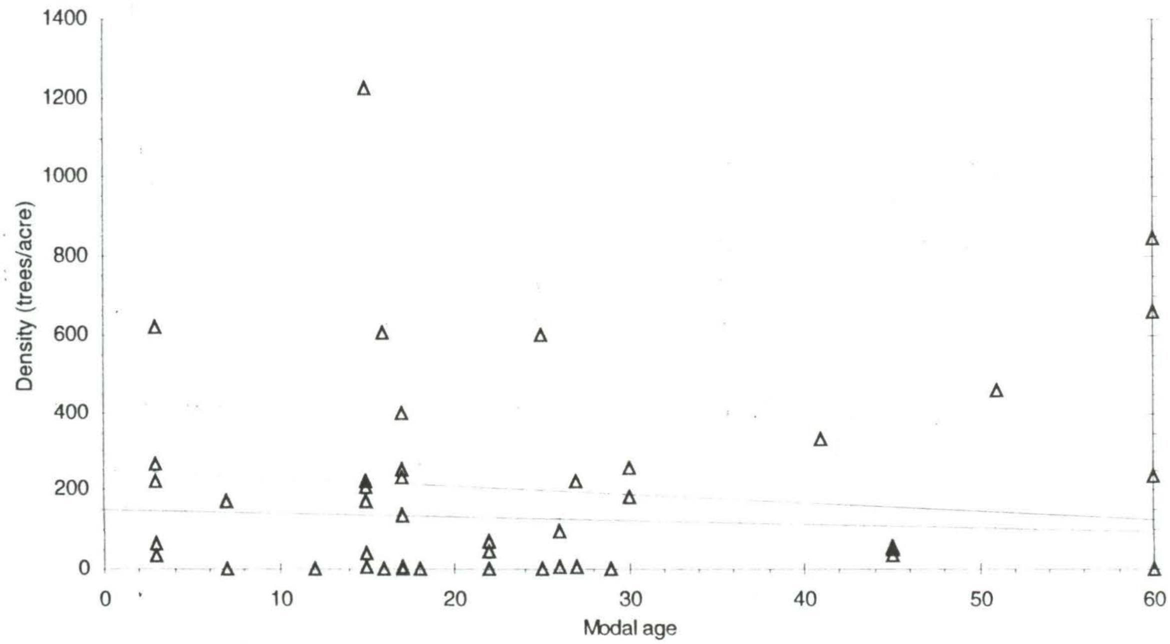

Figure 9. Close-up of Figure 8, showing only the treatment units and linear minimum density curves.

II.D. Factors

II.D.1. Treatment types

Like sites, I had to select treatments from the entire classification. From the treatment classification used in the database (Level 3) I lumped some treatment types and removed others, resulting in Level 2 of the treatment classification (Table 2, Table 6).

Each treatment type (or "treatment") in Level 2 of the treatment classification is a factor in the analysis. The treatment types are defined in Chapter 1.

Two types of values were assigned to the treatment factors for each treatment unit:

- counts, *i.e.*, the number of times the treatment was applied to the unit, and
- presence/absence, *i.e.*, whether or not the treatment occurred to the unit.

I did not take into account the timing of the treatments, relative to each other or to the time of year.

II.D.2. Stages

Stages are a broader classification of treatments than treatment types. Four stages (site preparation, propagation, release, and protection) are factors in some analyses. The relationship of stages to treatments is shown in Table 6; of course treatment types and stages are not used together in the same analysis.

The values assigned to each stage for each unit are:

- number of unique treatment types (of the stage) applied to the unit
- total number of treatment types (of the stage) applied to the units (multiple applications of a treatment type are counted),
- presence or absence of the stage on the unit, and
- the maximum or sum of intensity values for all treatment types (of the stage) applied to the unit (see below).

Intensity is a quasi-quantitative value assigned a code to each treatment category. It is based on my interpretation of relative intensity of the treatment, based not on any potential effect to pines, but rather to the entire ecosystem. I considered the duration of the effects and the extent of soil and vegetation disturbance. Treatment units assigned to intensity 0 were not considered to have no effect, rather they were not consistently recorded and needed to be removed from the analyses.

The values are ordinal, and a given intensity value is intended to represent the same level across all stages. (Some treatment types occur in more than one stage.) These rankings and the classification system are shown in Table 6.

Table 6. Treatment types (Level 2), stages, and intensity rankings.

	Stage			
Intensity	**Site preparation**	**Propagation**	**Release**	**Protection**
0*	Skidding	Natural seeding	Thinning	
1	Brush removal	Direct seeding	Brush removal	Exclosure
2	Fire (prescribed or wild)	Planting		
3	Felling			
4	Herbicide		Herbicide	
5	Cultural			
6	Mechanical site preparation			

*An intensity of zero means the treatment was not included in analysis. Skidding and natural seeding were not included because they were not consistently recorded. Most logged units were skidded, and many units, being in the vicinity of mature pines, were subjected to natural seeding whether or not it was relied upon. Thinning was not included because it was applied only after a unit had reached high regeneration standards.

II.D.3. Prepropagation Overstory

"Prepropagation overstory" is the condition of the tree canopy of a unit after any site preparation, but before propagation. I use "overstory" and "canopy" interchangeably to mean "tree stratum or strata." The *presence* of a canopy or overstory means that more than a few trees are present. Overstory and canopy are used as synonyms of "prepropagation overstory" unless otherwise specified. Because most factors are treatments, I often lump overstory factors under the general heading "treatments" in the text.

Prepropagation overstory was assigned qualitatively in the field. I used several related measures (Table 7):

- **overstory density:** an estimated ordinal rating of 0 (no canopy), 2 (scattered canopy), or 3 (dense canopy) that indicates the relative amount of tree cover. The value of "1" is not used because I believe the difference from "no canopy" to "scattered canopy" is greater than the difference from "scattered" to "dense" canopy. However, the qualitative range of cover represented by "scattered canopy" is large.
- **canopy:** the presence or absence of tree cover. A unit with a canopy (canopy present) may have a scattered or dense overstories density.
- **dense canopy:** the presence or absence of dense tree cover. A unit with a "dense canopy" also has a "canopy."

- **overstory code:** a rank from 1 (sparsely vegetated) to 9 (dense hardwoods), representing a physiognomic overstory classification that incorporates *overstory density* and the presence of *overstory pines.* Overstories containing pines were ranked lower than hardwoods, based on the hypothesis that these would be better pine regeneration sites.
- **overstory pine:** the presence or absence of tree-sized pines (pre-propagation) in the canopy.
- **stability:** a rank from 0 (low) to 2 (high), representing the degree to which I expect the vegetation to change over time: a clearcut is least stable due to resprouting, partial cuts (leaving a scattered canopy) are somewhat more stable, and old fields (which in Itasca seem to change quite slowly) and uncut (leaving dense canopy) are most stable.

Table 7. Measures of Overstory and their relationships. The measures are the columns and the rows are the values.

Overstory Code		Density	Canopy	Dense Canopy	Pine	Stability
1	sparsely vegetated	0	no	no	no	2
2	clearcut	0	no	no	no	0
3	sod	0	no	no	no	2
4	scattered pine	2	yes	no	yes	1
5	scattered pine + hardwood	2	yes	no	yes	1
6	scattered hardwood	2	yes	no	no	1
7	dense pine	3	yes	yes	yes	2
8	dense pine + hardwood	3	yes	yes	yes	2
9	dense hardwood	3	yes	yes	no	2

II.E. Methods

II.E.1. Field surveys

I estimated the density of each pine species in each unit in the summers of 1995 and 1996 using 1.6 meter wide transects (defined by my arm span). The transects were systematically placed, about 80 meters apart for most units, but as close as 20 meters apart for small units (<5 acres) and as far as 200 meters apart for large units (>50 acres). In this way an average of 9% of each unit was sampled (most <5%); larger sites had a lower sampling intensity (Appendix 4).

A pine was counted for the transect if the center of its stem fell within the transect width. The species and age, estimated by counting whorls, were recorded, as well as notes about the condition and spacing of the trees in the transect. The extent of competition around each pine was not estimated. Non-pine tree species and pines clearly older than the stand initiation age were not recorded except as notes.

I also recorded information about pines I could see outside of the transect. I noted the general abundance of pines, by species and age class, and the general condition and spacing of the trees. I looked for the following negative properties:

- clumped distribution
- stunted growth
- dull, light-colored needles
- readily visible presence of disease
- missing or damaged leader or candles (current year's growth)

After walking all the transects of the unit I used my observations to assign a subjective status rank, from 0 (no regeneration) to 3 (very good), to each species. This rating contributed to my overall assignment of status, as described in the status section.

A few older units were planted in rows, which could bias density results but not my overall assignment of status. The only units in which rows were obvious were OBRC and LAT, and in these I aligned my transects neither parallel nor perpendicular to the rows. Headwater's Parking Lot (HPL), also obviously planted in rows, was sampled using a different method: a census of a 100 m^2 (0.025 acre) plot chosen to be characteristic of the unit.

A few densities were taken from the literature rather than the field, and therefore represent densities at earlier years and possibly reflect a bias of different sampling methods. These are described in Table 8.

Table 8. Treatment units not sampled in 1995 or 1996.

Treatment unit(s)	Source of density data	Year
Big Pine 2 (BP2)	Paul Rundell said there were no pines.	1994
CCC Plots 2 and 3 (CC2,CC3)	Thoma (1988) walked the sites and found no pines.	1988
Mary Lake Exclosure (MLEF, MLEU)	Steingraber (1989) censused pines >0.15 meter tall in the extent of both units.	1984
Forestry Demonstration Area–Monitored (FDAM)	A draft of the Forestry Demonstration Area brochure draft found in H. Hansen's files gives the density just before the 1970 thinning.	1970

II.E.2. Analysis Methods

This study is not designed, and data are therefore not ideal for statistical analysis. However, I can still make generalizations about the group of selected units, though I cannot generalize about a larger population.

II.E.2.a. Density and status of treatment units

For the analysis I used total pine density without 1-year-old trees, but I also present densities including 1-year-olds. Trees too old to be a result of treatments are excluded from the density calculation, but all trees of stand initiation age and younger are included, including trees that, based on their age, are clearly not an immediate result of treatments.

<u>Change in density over time</u>

At least 23 units (comprising 16 supersites) were surveyed for density at some time before my 1995-96 surveys. I use these results to show how pine density has changed over time on these units:

$$\text{rate of density change} = \frac{\text{change in density (pines / acre)}}{\text{change in age (years)}}$$

II.E.2.b. Density of pine regeneration in treatment units and established natural pine stands

Kurmis (1969) surveyed natural pine regeneration (2-15 year old seedlings and saplings) under 6 forest types in Itasca State Park, in 1965: jack pine, jack pine - red pine, pine - fir - spruce, red pine, oak - aspen - birch, and maple - basswood - white pine. (The *overstories* of these stands were some of the natural pine stands used in defining status ranks. In this analysis I used only the pine regeneration.) I compared these natural regeneration density results to those of the managed units in my study.

II.E.2.c. Frequency of treatment application by managers

To summarize the kind of work that has been done at Itasca, I compared the application frequency of the 11 treatment types[4] using the following values to represent the relative amounts of application of each treatment:

1. the number of units (out of 59) to which each treatment type was applied
2. the proportion of application of each treatment type relative to all treatment applications

An application of a given treatment type to a given unit was counted only once, even if the treatment was applied more than once to the same unit. For this analysis I am not interested in

[4] The 3 treatment types of zero intensity (Table 6) are not included in analyses.

the number of times a treatment was applied to a particular unit, because some treatment types (particularly planting, herbicide release, and fire) are routinely reapplied, and others are not.

I repeated these calculations grouping the 11 treatment types into the 4 stages (the columns of Table 6), and used the first calculation to show the canopy condition of the 59 units.

II.E.2.d. Treatment associations

Another aspect of the Itasca treatment history is the frequency at which treatments occurred together (or not together). There are 2 purposes for showing the treatment pair relationships:

1) to show which pairs were "favored" or "disfavored" by managers, and

2) to show treatment associations which could affect interpretation of treatment vs. status analyses; the relation of an individual treatment to status is less meaningful if other treatments were commonly applied (or not applied) to the same units (*i.e.*, are associated).

I used contingency tables to test the null hypothesis of independence of each pair of treatments. Two canopy variables—*canopy* and *dense canopy* (see p. 56)—are included together with the treatments.

II.E.2.e. Relationship of individual treatments to status

I used contingency tables and indicator analysis to look for associations between individual treatments and status. Association does not equal causation, but, when combined with other data, can aid in an understanding of the effectiveness of a treatment. Combinations of treatments are considered in later sections.

Contingency tests of treatment with status

I used one contingency table per treatment to test the association of each treatment to status. The χ^2 test is normally used to test the null hypothesis that there is no association between 2 factors in the *population*. I used it instead to test the strength of associations in the sample, as there really is no population.

The treatment values for this analysis are presence/absence; the canopy and dense canopy factors were included as treatments. Status B units were combined with Status A units in order to make the "status" variable yes/no.

Indicator analysis

Indicator analysis is a method of finding indicator species for community types or environmental variables. In the method of Dufrene and Legendre (1997), as used in PC-Ord (McCune & Mefford 1997), an indicator value is assigned to each species for each predetermined group based on the degree to which it discriminates among the groups. The calculation is based on the mean abundance of a species in a group divided by its mean abundance across all groups, and the frequency of the species in each group. The indicator values range from zero (no indication) to 100 (perfect indication, the species points to the group without error).

The maximum indicator value for each species can be used to compare species for reliability as indicators. PC-Ord uses the Monte Carlo method to test, for each species, if the maximum of the indicator values is statistically significant. The null hypothesis is that the indicator value is no larger than expected by chance.

Instead of species, I used this method to find indicator *treatments* for high- and low-status units. The calculation is as follows:

$$\frac{\text{mean treatment count of Treat1 in GroupA}}{\text{sum of all mean treatment counts in GroupA}} \times \frac{\text{\# of GroupA units to which Treat1 applied}}{\text{total \# of units in GroupA}} \times 100$$

The result of the analysis is 3 indicator values per treatment, one value for each status level. The maximum of the 3 values is tested for significance.

I tested 13 treatments[5] and 4 measures of overstory in this analysis. For treatment "abundance" on each unit, I used the number of times the treatment was applied to the unit. The 4 overstory variables are overstory code (1-9), density (0-3), stability (0-2), and pine (yes/no).

II.E.2.f. Relationship of individual stages to status

Indicator analysis

I performed indicator analyses on count data for the 4 stages, alone and combined with 2 overstory variables: overstory code (1-9) and density (0-3). For information about this analysis, see the description of indicator analysis of individual treatments above.

Stage abundance

Summary statistics (average, median, mode, range) are used to compare the "amount of treatment," by stage, of high, low, and medium-status units. For each stage, the following values are summarized across units:

- the maximum of the intensities of treatments in the stage applied to the unit
- the sum of all intensity values for treatments in the stage applied to the unit (multiple applications of a given treatment type on a unit are added in each time)

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[5] The 2 extra treatments, blading and wildfire, are combined with mechanical site preparation and prescribed fire, respectively, in most analyses.

- the total number of applications of all treatments in the stage (multiple applications of a treatment type are counted each time)

The concept of *intensity*, a quasi-quantitative value assigned to each treatment type (Table 6), is described in the Factors section, above (p. 55).

II.E.2.g. Classification of units by treatments, and relation to status

Using a variety of methods I grouped treatment units based on the treatments that occurred to them, and I looked for a relationship of status to these groups of units. Some of the cluster analyses (treatment counts with overstory code and with density+pine+stable) include an extra site, Old Bemidji Road–Road (OBRR), before it was dropped as a unit.

Multi-Response Permutation Procedures (MRPP) is not a classification tool, rather it is a non-parametric test of an existing classification based on factors unrelated to the classification parameters. I used it to test the classification of units by status level. Using different treatment measures (counts or presence/absence with and without different overstory variables), I grouped units based on status and tested for a multivariate difference in treatment "composition" among the groups. In PC-Ord (McCune & Mefford 1997), I used the Sørenson distance measure; items in a group are weighted based on the size of the group.

Cluster analysis is typically used to classify *stands* by *species composition*. Instead I classified *treatment units* by *treatment "composition."* I generated several different classifications using different treatment measures (counts or presence/absence with and without different overstory variables).

Cluster analysis groups "stands" (treatment units) using a multivariate distance metric. The PC-Ord (McCune & Mefford 1997) algorithm is hierarchical, agglomerative (bottom-up), and polythetic. I used Ward's method with a Euclidean distance measure.

The result of a cluster analysis is a dendogram showing a hierarchical grouping of units (Figure 10). I studied the dendograms to determine if promising units were grouped together, concentrating on the coarsest grouping (see Figure 10) of units. Of this grouping I called one group "Promising" and one group "Unpromising," based on the status rating of the majority of units in the group (and ignoring medium-status units). On each group I used 2 quantitative measures of classification "quality" based on status:

uniformity = % of units in Group 1 with Status Level 1

grouping = % of units in Status Level 1 in Group 1

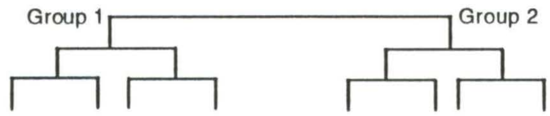

Figure 10. A prototype dendogram. I call the grouping of units into "Group 1" and "Group 2" the coarsest grouping.

Manual classifications: I manually performed some divisive (top-down) classifications of the units. Instead of polythetic methods, I divided the units into groups, one treatment at a time, using presence/absence data. I created several classifications using the following methods to order the treatments:

- treatment indicator strength,
- apparent importance of treatments in cluster analysis results,
- apparent importance of treatments in status vs. treatment contingency table results, and
- ability of treatments to divide promising from unpromising units (as determined by trial and error).

From these classifications I chose those that most cleanly reflect the status of the units.

II.E.2.h. Ordination

I used the following ordination methods on several representations of the data (see Factors, p. 55) to look for patterns of units and their possible relation to status:

- Non-Metric Multidimensional Scaling (NMS), an ordination method for non-normal data
- Detrended Correspondence Analysis (DCA or DECORANA), the most commonly used ordination for ecological data
- Bray-Curtis Ordination (Polar Ordination), the original and simplest ordination method

Results are not included because they did not add any information to the classification results.

II.E.2.i. Intraproject comparisons (Results & Discussion)

A brief description of the treatments applied to each unit is given, along with a discussion of possible reasons for the status of the unit. The units are grouped so as to compare the effects of particular treatments on pine regeneration. They are grouped first by **supersite** so that subsites (such as a fenced area and a control) may be compared, and then by **treatment types** of interest (exclosures, burned units, cultural units) so that the results may be compared. In these comparisons I rely more on the concept of *improved* pine density or condition (in response to a treatment or treatments) than on "status."

II.F. Results

These results are generalizations of data for the selected treatment units and may or may not apply to the entire set of restoration activities of the past or future.

II.F.1. Density and Status

The pine regeneration density of the 59 units ranged from 0 to 1,225 pines/acre, with an average of 163 pines/acre. The modal density was zero; 22 of the 59 units (37%) had no observed pine reproduction. The density and status rank of each unit is shown in Table 9 (p. 66).

Of the 59 treatment units, 17 (29%) are Status A (promising), 5 (8%) are Status B (medium), and 37 (63%) are Status C (unpromising). If Status B units are lumped with Status A, 22 (37%) of the treatment units are "promising."

The density range was 98 to 1,225 pines/acre for Status A units, 170 to 268 for Status B units, and 0 - 239 for Status C units (Figure 11).

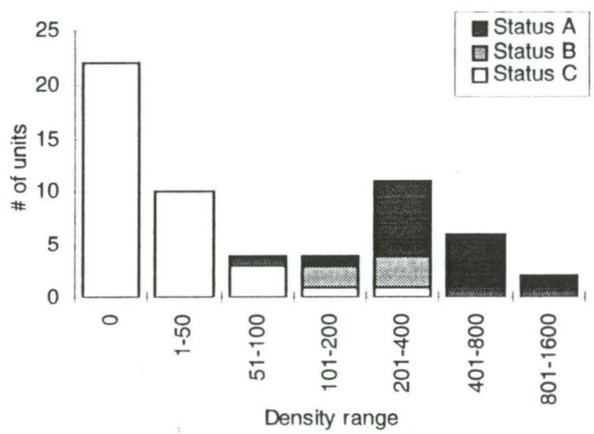

Figure 11. Number of units by density range and status rank.

The graph used to assign status is shown in Figure 12, this time showing the final status rank assignments. As shown, not all units were assigned based on the minimum density curves. The exceptions are:

- R13 (Red Pine 13) is just above the top line with a density of 268 pines/acre at 3 years, but its status rank is "medium." The preexisting natural pine regeneration of this unit is extremely clumped. The 3-year-old trees were planted only the year before I surveyed, and the condition (and survival) of these trees was questionable. The site is mostly open and it is my subjective impression that this unit will not develop a pine tree canopy without significant additional plantings.

- JP1U (Jack Pine 1–Unfenced) is on the bottom line with a density of 135 pines/acre at 17 years, but it is rated "unpromising." All of the pines are stunted, and none is over a meter high after 17 years. It is unlikely that many will ever grow above their susceptibility to deer browse.
- OBRC (Old Bemidji Road–Cut) is just below the bottom line with a density of 98 pines/acre at 26 years, but it is rated "promising." The site looks excellent. The lower density may be an artifact of my sampling of the unit; the pines are still clearly in rows. There were many pines just outside of my transects.
- MLEU (Mary Lake Exclosure–Unfenced) is well above the top line with a density of 239 pines/acre at 60 years, but it is rated "unpromising." Almost all of the pines are stunted (less than 2.1m tall) and none is more than 20 years old. As it has been 60 years since treatment, it is unlikely that a significant number of pines will reach the canopy.

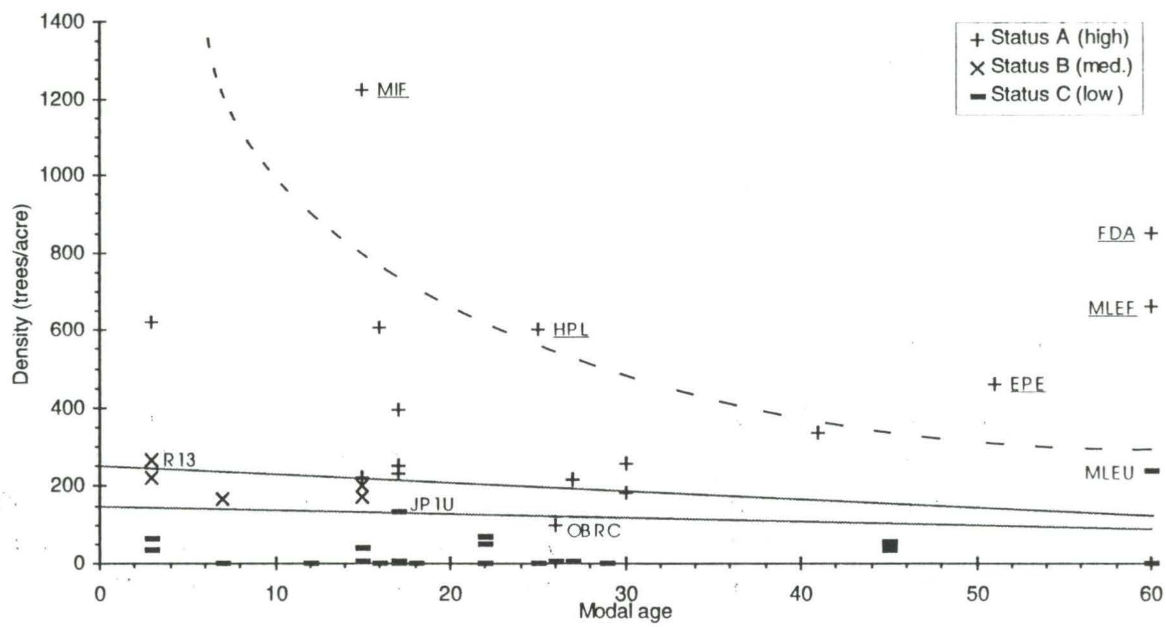

Figure 12. Density and age of high-, low-, and medium-status units. The minimum density lines (solid) guiding status assignment are shown. The units for which subjective pine condition factors overrode the density guidelines are labeled (no underline, see text for explanations). The approximate ideal minimum density curve (dotted) is also shown, and the 5 units which would be high-status based on the ideal criterion are labeled and underlined.

Table 9. Treatment units with pine reproduction density, grouped by status rank. Density is shown both with and without one-year-old trees. "Age" is the modal age of all pines that originated after first management of the unit. For full treatment unit names and species-specific densities, see Appendix 4. For treatment unit locations see Appendix 5.

A (high)		Density (pines/acre)		
Unit	Age	inc. age 1	w/o age 1	Status
ECSE	16	631	604	A
ECSW	16	631	604	A
EPE	51	457	457	A
FDAM	60	848	848	A
HNE	30	187	181	A
HPL	25	600	600	A
HSE	30	256	256	A
JP1M	17	240	231	A
JP1N	17	263	251	A
JP1Y	17	426	396	A
JPDF	3	682	619	A
LAT	41	368	334	A
LGEF	27	219	219	A
MIF	15	1233	1225	A
MLEF	60	659	659	A
OBRC	26	98	98	A
SMF	15	234	221	A

B (medium)		Density (pines/acre)		
Unit	Age	inc. age 1	w/o age 1	Status
CFOF	7	196	170	B
JPDC	3	221	221	B
MIR	15	199	172	B
R13	3	268	268	B
TPFW	15	256	204	B

C (low)		Density (pines/acre)		
Unit	Age	inc. age 1	w/o age 1	Status
BP1H	17	0	0	C
BP1Y	17	0	0	C
BP2	12	0	0	C
BP3D	12	0	0	C
BP3U	12	0	0	C
CC2F	60	0	0	C
CC2U	60	0	0	C
CC3	60	0	0	C
CFOC	7	0	0	C
DS21	45	35	34	C
DS22	45	73	49	C
DS3	45	53	53	C
ECSU	16	0	0	C
JP1U	17	139	135	C
JR2	15	3	3	C
LBAC	22	602	69	C
LBAF	22	47	47	C
LGEU	27	3	3	C
LGWM	26	5	5	0
LGWS	26	5	5	C
MLEU	60	239	239	C
OPE	29	0	0	C
RHH	3	35	35	C
RP4	3	65	65	C
SLEE	18	0	0	0
SLEN	18	0	0	C
SLER	18	0	0	C
SLEW	18	0	0	C
SLW1	22	0	0	C
SLWM	22	0	0	C
SLWS	22	0	0	C
SLWW	22	0	0	C
TPFE	15	51	38	C
TSTD	25	0	0	C
TSTM	25	0	0	C
WPKC	17	0	0	C
WPKF	17	6	3	C

II.F.1.a. Change in density over time

The average change in density for the 23 monitored units is -140 pines/acre/year, with a range of -2,174 to 26 (Table 10). For the 6 *promising* monitored units, the variation in rate of density decrease is fairly low (Figure 13); the average is -9.2 trees/acre/year, with a range of -15.5 to -6.1. For the 9 *unpromising* monitored units, however, the variation is quite large; the range is -2174 to 0 trees/acre/year, with an average of -288. (The rate of –2174 pines/acre/year is for Sewage Lagoon West which had a pine seedling density of 50,000 pines/acre following fire and disking.)

Table 10. Average rate of change in density, in pines/acre/year, for each status level.

		Change in density		
Status Level	**n**	**Mean**	**Min.**	**Max.**
C (unpromising)	9	-288	-2174	0
B (medium)	8	-72	-152	26
A (promising)	6	-9.2	-15.5	-6.1
A + B	14	-45	-152	26
overall	23	-140	-2174	26

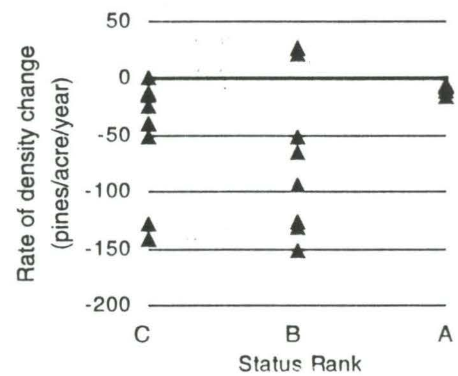

Figure 13. Change in density in pines/acre/year for 22 units. (One -2174 rate falls off the graph.)

II.F.2. Density of pine regeneration in treatment units and established natural pine stands

In Kurmis's (1969) 1965 survey of natural pine regeneration, the highest average pine reproduction density was in "jack pine" stands, with 2,443 pines/acre. The regeneration density was much lower under the other 5 upland forest types: 304 pines/acre in "maple-basswood-white pine," 238 in "jack pine-red pine," 109 in "red pine," and 93 in "pine - fir - spruce" (Figure 14). There was no pine reproduction in the "oak - aspen - birch" stands. In all types but jack pine there was at least 1 stand with no reproduction.

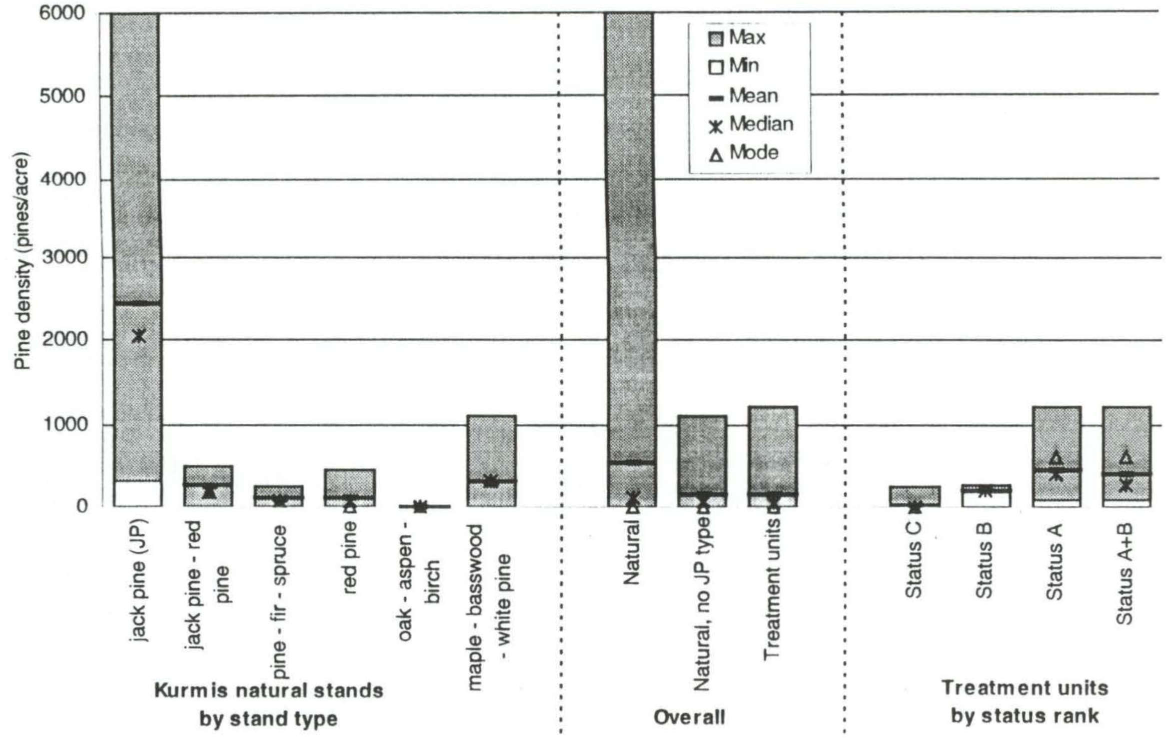

Figure 14. Pine density statistics by Kurmis's (1969) natural stand type and treatment unit status level. Overall summaries for both data sets are shown in the center of the figure. (Two summaries are shown for the natural stands: all stands and all stands except jack pine type stands.)

Most of the high natural reproduction values come from "jack pine" type stands; of the 6 natural stands with a reproduction density of more than 500, 5 are of the jack pine type. Therefore, I have compared the treatment unit densities to the natural densities both with and without the jack pine stands. According to Kurmis (1969), the type is relatively rare in Itasca.

<u>Comparisons with jack pine type included</u>

The overall range of pine reproduction densities (per stand) in Kurmis's survey is 0 to 6,000 trees/acre, with a mean of 534 trees/acre, a median of 120, and a mode of 0 (Figure 14). The pine reproduction in the managed units of my study is much lower (Figure 14), with a range of 0 to 1,225 trees/acre, an overall mean of 163, a median of 38, and a mode of 0.

The percentage of stands with no reproduction (Figure 15, density = 0) is the same in both Kurmis's natural stands (36%) and the treatment units (37%). However, the densities of the remaining stands are more often higher in the natural stands than in the treatment units. In particular, there are more natural stands that would be considered "promising" using a simple density cut-off of 100 or 200 trees/acre: 53% and 39% of natural stands have a reproduction density greater than 100 and 200 pines/acre, respectively; compared to 39% and 32% of treatment units greater than 100 and 200 pines/acre.

Comparisons without jack pine type

When jack pine stands are removed from the calculations, the reproduction density of the remaining natural stands (mean 152, maximum 1,100, median 60) is slightly lower than the reproduction density of the treatment units (Figure 14). Without the jack pine type stands, 43% and 27% of natural stands have a reproduction density greater than 100 and 200 pines/acre, respectively (Figure 15).

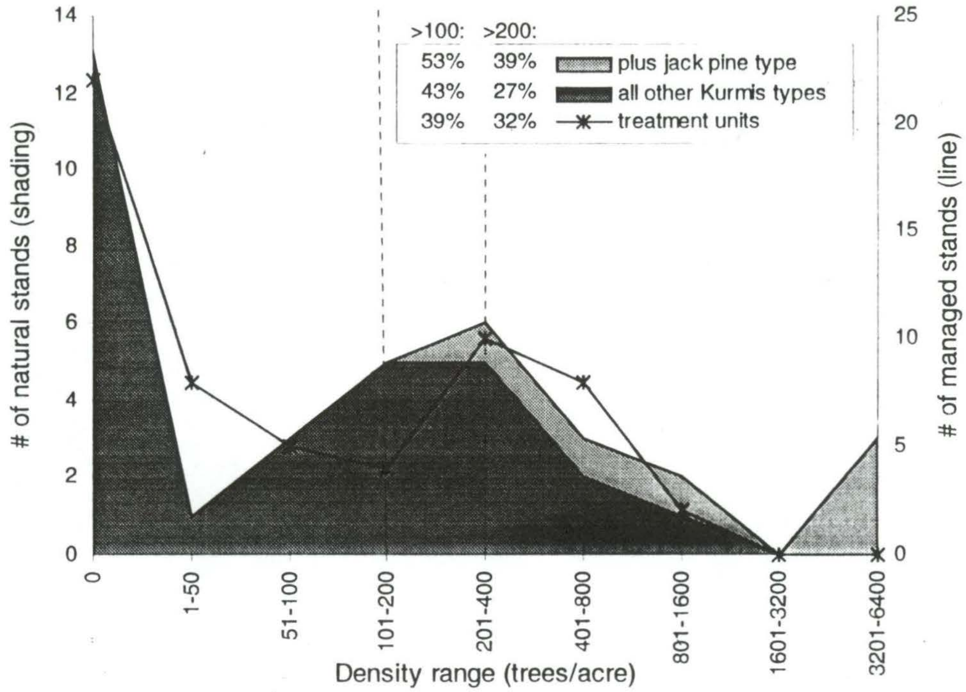

Figure 15. Frequency of pine reproduction densities in natural stands (area, Kurmis 1969) and treatment units (line, current study).

While the management efforts do not appear to appreciably increase the *density* of pine reproduction over what was found in natural stands in 1965, it does appear to increase the *condition* of this reproduction. The natural regeneration was highly stunted; saplings (1"-4" DBH) were very rare, and many 15 year old seedlings had not reached the height of 1 foot (Kurmis 1969). In contrast, at least some of the treatment units have pines reaching the sapling and even canopy classes.

II.F.3. Frequency of treatment applications by managers

The application of the 11 treatment types to the 59 treatment units results in 208 unique treatment type - treatment unit combinations ("treatment applications") when each treatment type is counted only once per unit. The frequency of application of each treatment types is shown in Figure 16. Felling, planting, and seeding together comprise over 50% of the 208 treatment applications, each with a frequency of about 17%. Mechanical site preparation and fire (including the 1 wildfire) were equally "favored," at about 10% of all treatment applications. Fencing was applied to only 14 of the 59 units[6] (Figure 16 inset *a*), and comprises only 7% of all treatment applications.

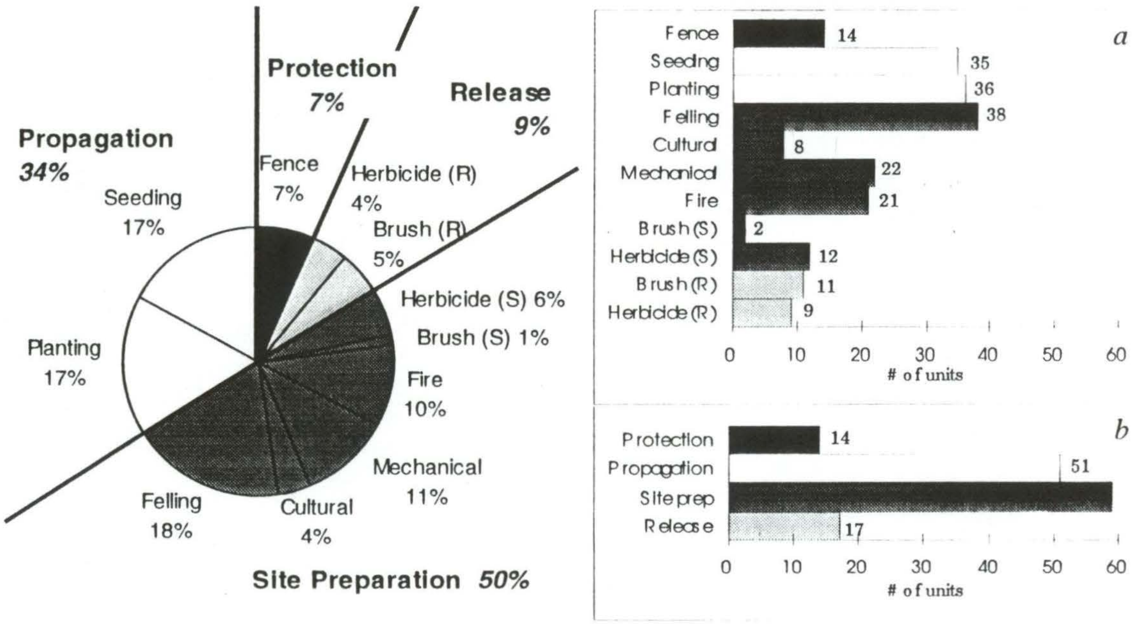

Figure 16. Frequency of treatment applications to the 59 selected treatment units. Each treatment type is shown together with its frequency of application. Frequency is calculated by dividing the total number of treatment units to which a treatment was applied by the total number of treatment - treatment unit combinations. Treatment categories of the same stage [(S)ite preparation, Propagation, (R)elease, and Protection] are grouped together. *Inset a:* the number of units to which each treatment type was applied. *Inset b:* the number of units to which each stage was applied.

Site preparation comprises 50% of all treatment applications, propagation 34%, release 9%, and protection 7% (Figure 16). All units were site-prepped (Figure 16 inset *b*) and most were propagated. But only 17 (29%) of the 59 treatment units were released and 14 (24%) were protected[6] (Figure 16 inset *b*), despite managers listing shrub/hardwood competition as problematic for at least 26 units and deer browsing as problematic for at least 33 units.

[6] Though there are 14 fenced units, there are only 11 fences; some units are contained within the same fence.

Regarding the condition of the pre-propagation overstory, 44 (75%) of the 59 treatment units had a tree canopy at the time of propagation (Figure 17); 31 (53%) of these had a scattered canopy and 13 (22%) of these had a dense canopy. Tree-canopy pine was present in 61% of the units. 15% of the units had low stability (0), 53% had medium stability (1), and 32% had high stability (2).

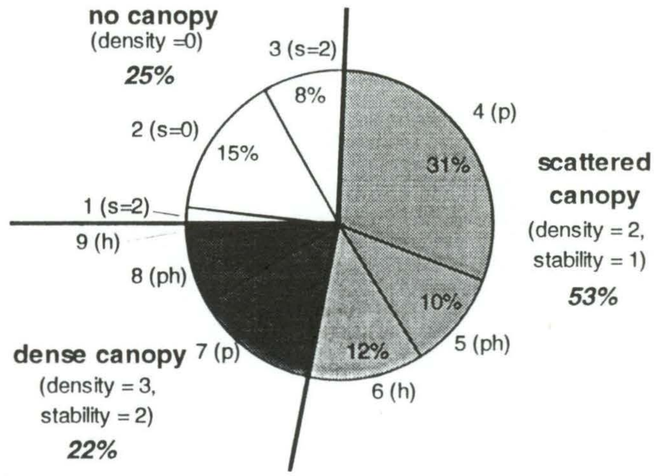

Figure 17. Proportion of units with each overstory code (1-9) and density (0-3) value. p=pines present, h=hardwoods present, s=stability.

II.F.4. Treatment associations

Relationships among treatments are shown in Figure 18, along with results of chi^2 tests of independence for each treatment pair. Here, unlike the previous section, 2 canopy variables (canopy and dense canopy) are included together with the treatments. For most treatment pairs, one treatment would typically occur before the other, but I've made no attempt to indicate this in the figure. The 2 canopy variables are shown first, followed by the treatment variables in descending order of frequency (from previous section). There are 2 purposes for showing the treatment pair relationships:

1) to show which pairs were "favored" or "disfavored" by managers, and
2) to show treatment associations that could affect interpretation of treatment vs. status analyses.

<u>Purpose 1:</u> The frequency of application of each treatment pair, *i.e.*, the percent of the 59 units to which both treatments in a pair were applied, can be seen in Figure 18 as the overlap in each pair of bars relative to the maximum possible height (59). Of course, the treatment pairs with the highest frequencies are most likely to be those with high frequencies individually.

Among the 10 most frequently applied treatment pairs, canopy is a part of 5, because 75% of units had a canopy. These pairs are: canopy and seeding (both were applied together to 54% of units), canopy and felling (51%, *i.e.*, 51% of units were partially cut), canopy and planting (37%), canopy and fire (31%), and canopy and mechanical site preparation (29%). The other, more interesting high-frequency pairs are felling and planting (both were applied to 49% of units), felling and seeding (46%), seeding and planting (36%), seeding and fire (32%), and fire and felling (31%).

Several low-frequency pairings of high-frequency treatments are of interest: dense canopy and planting never occurred together, mechanical site preparation and brush release were applied together to only 2 units (3%), brush release and dense canopy were together on only 2 units (3%), and fire and exclosure were applied together to only 4 units (7%). Cultural units (14% of all units) were never fenced, burned, or released (mechanically or chemically), they were never prepared by herbicide and rarely by mechanical site preparation (3 units or 5% of all units), only 1 was seeded (2% of all units), and, by definition, none was felled or had a dense canopy.

Purpose 2: A contingency test for each pair was used to test the null hypothesis that the 2 treatments are independent. Significant tests, those where the null hypothesis is rejected, are marked in Figure 18 with a + or –, showing the positive or negative character of the association.

Some treatment associations are due simply to the definition of the treatments. The 2 overstory variables shown in this section, *dense canopy* and *canopy* (yes/no variables), are related because if a unit has a dense canopy, it also has a canopy. (Most other analyses use only one overstory variable.) The condition of the overstory is also related to treatment (or lack of treatment) of the overstory (felling or cultural) prior to propagation. Only 2 units with a dense canopy were cut (selectively), and only 3 cultural units have a canopy (none has a dense canopy). There is no relationship between canopy and felling, however. Because felling and cultural are the only overstory treatments, they have a negative association, *i.e.*, no cultural units were cut.

The treatment relationships with significant χ^2 tests, along with some non-significant relationships of interest, are described here. The percents used are *not* based on all 59 units, but rather are based on the frequency of one treatment in the pair. χ^2 values are given if the relationship is significant ($p \leq 0.05$); the value is an indication of the strength of the relationship.

Canopy is associated with most treatments, because 75% of the units had a canopy. Almost all seeding (89%, $\chi^2 = 8.83$) and prescribed fire[7] (90%) occurred under a canopy (while 25% of seedings and 20% of fires occurred under a dense canopy). The only 2 units site-prepared by brush removal were under a dense canopy (7.33*). Exclosures (86%) and mechanical site preparation (77%) were also mostly under a canopy, though primarily a scattered

[7] No prescribed fire removed a canopy.

* At least one expected value is less than 5.

one. However, planting is negatively associated with canopy ($\chi^2 = 8.83$): even though 61% of planted units had a canopy, all but one of the units with no canopy were planted, and no units with a dense canopy were planted ($\chi^2 = 26.10$).

Felling is positively associated with planting ($\chi^2 = 8.61$) and prescribed fire ($\chi^2 = 7.71$). Although most prescribed fire (90%) occurred under a canopy, only 2 fires were on uncut units. All brush release ($\chi^2 = 6.93$*) and herbicide release ($\chi^2 = 5.45$*) occurred to cut units.

Planting, which is negatively associated with canopy, is also, not surprisingly, positively associated with felling ($\chi^2 = 8.61$) and cultural; 81% of planted units had been felled (and 74% of felled units were planted) and all but 1 cultural units were planted. All 9 herbicide releases occurred to planted units (6.78*). Most brush removal releases were to planted units, but only 56% of planted units were released by at least 1 of the 2 release methods. Only 28% of planted units were treated with prescribed fire and only 25% were fenced.

Seeding, in addition to being associated with canopy (see above), is positively associated with prescribed fire ($\chi^2 = 14.69$; only 1 burned unit was not seeded) and fencing ($\chi^2 = 4.71$; all but 2 exclosed units were seeded). It is negatively associated with herbicide site preparation ($\chi^2 = 4.85$*) and cultural ($\chi^2 = 9.16$*).

Mechanical site preparation is not significantly associated with any other treatment or canopy condition.

Prescribed fire, as shown above, is associated positively with felling and seeding. Also, no cultural units were burned (4.75*) and both site preparations by brush removal were before fire (4.04*). Only 20% of burned units were fenced and only 25% were released by brush removal and 18% by herbicide treatment. 50% of burned units were planted.

Exclosure (fence), as shown above, is associated positively with seeding. Also, site preparation by herbicide was never done to a fenced unit (4.69*). Most (79%) fenced units were also cut, but 86% had a canopy and 29% a dense canopy. Only 64% of fenced units were planted. No cultural units were fenced.

Brush release, as shown above, only occurred to cut units. It is also positively associated with site preparation by brush removal ($\chi^2 = 9.03$*). Of the 11 brush-released units, 82% were planted, most had mechanical or herbicide site preparation, and none was cultural.

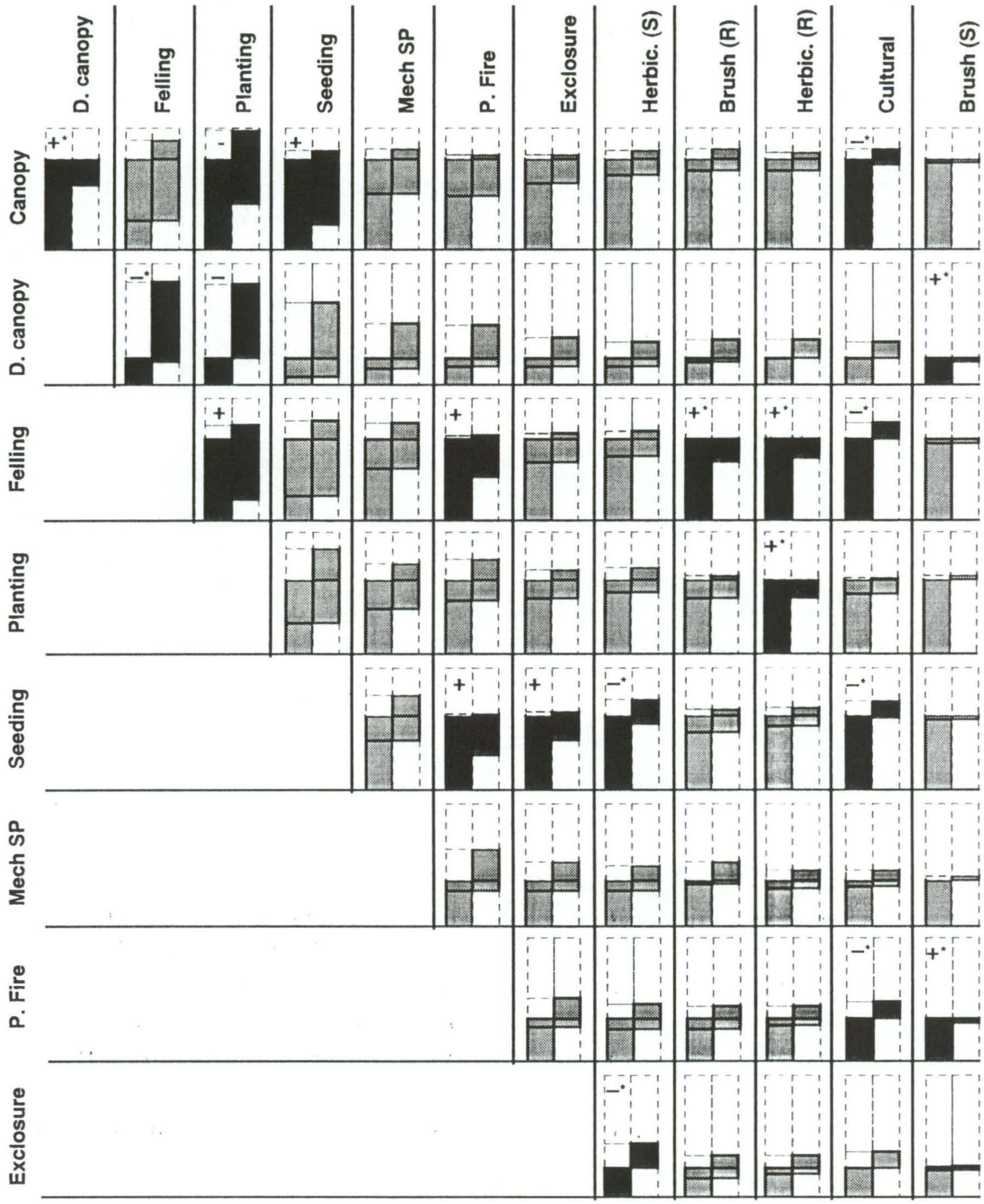

Figure 18. Relationships of treatment pairs. In each pair of bars, the left bar is the *column* treatment and the right bar is the *row* treatment. The shading shows the number of units to which the treatment occurred; the overlap of a pair of bars represents the units to which *both* treatments occurred. Significant χ^2 tests (p < .05) are indicated by darker shading and a + (positive association) or – (negative association) above the left bar of the pair. *at least one expected value is < 5. *D. canopy* = dense canopy, *Mech SP* = mechanical site preparation, *P. Fire* = prescribed fire, *Herbic* = herbicide, (S) = site preparation, (R) = release.

II.F.5. Relationship of status to individual treatments

This section describes the relationship between individual treatments and status. The previous section (treatment pair relationships) shows why these results must be interpreted cautiously. An observed association of a treatment with status could be a real effect of the treatment, but could also be a result of other treatments and conditions that tend to occur at the same time as the treatment. Combinations of treatments are considered in later sections.

II.F.5.a. Contingency tests of treatments with status

One contingency test was performed for each treatment. The 4 proportions ("cells") for each test (treatment applied/Status A or B, treatment applied/Status C, treatment not applied/Status A or B, and treatment not applied/Status C) are shown graphically in Figure 19. The significant tests are marked.

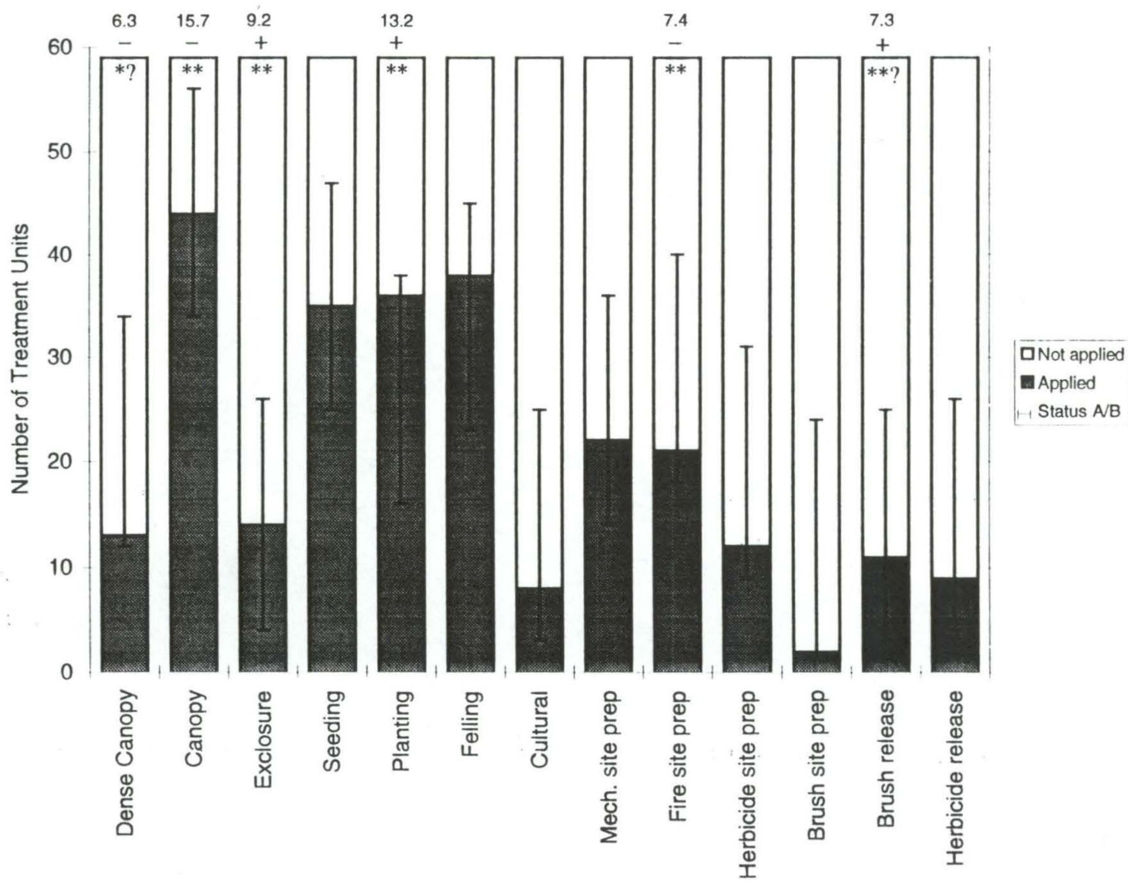

Figure 19. Number of treatment units to which each treatment was and was not applied, and the high-to-medium portion (Status A & B) of each group. Each bar represents the 59 units and is divided into the 4 "cells" of a contingency table (from bottom to top): (1) Status C, treatment applied; (2) Status A/B, treatment applied, (3) Status A/B, treatment not applied, and (4) Status C, treatment not applied. χ^2 test results are at top of bars: ** = p<0.01, * = p<0.05, ? = an expected value < 5, + = positive association, – = negative association. χ^2 value shows the relationship strength.

The strongest association (based on χ^2 values) of the 13 contingency tests is the presence of canopy cover, which is negatively associated with Status A/B (medium- to high-status). Planting and exclosure are positively associated with Status A/B, and site prep by fire (including the 1 wildfire) is negatively associated with Status A/B. Brush release appears to be positively associated with Status A/B, and dense canopy appears to be negatively associated; however results of these 2 tests are unreliable due to an expected value less than 5. The remaining test results were not significant.

"Dense canopy" shows a weaker association with Status A/B than "canopy," because there are many fewer units with a dense canopy (75% of all units have a canopy and 22% have a dense canopy). Of Status A/B units, 41% did have a canopy but only 1 (6%, Mary Lake Deer Exclosure) had a dense canopy.

Some proportions for the remaining treatments with significant χ^2 test are:

- Planting: Of all units, 61% were planted. Of these, 56% are Status A/B, but 91% of Status A/B units were planted and only 9% of unplanted units were promising.
- Exclosure: Of all units, 24% were fenced. Only 45% of Status A/B units were fenced, but 71% of the fenced units are Status A/B and only 27% of unfenced units were Status A/B.
- Fire site preparation: Of all units, 36% were prepared by fire (34% by prescribed fire). 86% of fire units (90% of *prescribed* fire units) were Status C and only 14% of Status A/B units had site preparation by fire (9% had *prescribed* fire). 50% of units without fire were Status A/B.
- Brush release: Of all units, 19% were released by brush removal. Only 36% of Status A/B units had brush release. However, 73% of the brush released units were Status A/B and 71% of units without brush release were Status C.

From these results it is clear that the presence or absence of no single treatment can predict the status of a unit. For example, 91% of unplanted units were low status, but only 56% of planted units were medium- to high-status. In other words, it may be a good idea to plant, but that is not the only thing that is needed to ensure pine regeneration.

II.F.5.b. Treatments as indicators of status

The indicator values of each treatment for each status rank are shown in Table 11. Only the maximum indicator value for each treatment was tested for statistical significance.

Table 11. Indicator values for each treatment at each of the (*a*) 3 status levels and (*b*) 2 status levels with the 5 medium-status units removed. Indicator values range from 0 (no indication) to 100 (perfect indication). Treatments are listed in descending order of maximum indicator value (*shaded*) for analysis *a*. The statistical significance of the maximum indicator value for each treatment in each analysis is shown (= p<0.01, * = p<0.05).**

	Indicator analysis *a*			Indicator analysis *b*	
Treatment	High status	Med. status	Low status	High status	Low status
Planting	51*	23	8	66**	11
Density[§]	9	17	47**	12	65**
Cultural	2	45**	1	7	3
Overstory code[§]	24	32	44**	36	64**
Stability[§]	12	44*	34	22	60*
Prescribed Fire	1	0	43*	1	43**
Pine[§]	11	10	35	15	47
Exclosure	33	5	1	44**	2
Felling	32	9	23	41	30
Seeding	12	19	28	18	42
Herbicide release	22	0	3	22	3
Brush release	19	9	1	36**	1
Mechanical	11	14	13	17	20
Herbicide site prep	10	0	10	10	10
Wildfire[†]	6	0	0	6	0
Brush site prep	0	0	5	0	5
Blading[†]	0	0	3	0	3

[†]These 2 treatments are lumped with other treatments in most analyses.
[§]These "treatments" are actually overstory variables.

Analysis with 3 levels of status (a)

The treatment with the highest maximum indicator value is *planting*; it has an indicator value of 51 for promising units; *i.e.,* in my sample, planting is an indicator of Status A. The next best indicator is overstory *density*. For Status C units it has an indicator value of 47. *Overstory code* is close behind as an indicator of Status C (44% indication).

Cultural treatment is the next best indicator, with a maximum value of 45. However, this value is for Status B units, and therefore does not mean much in terms of predicting the future of a unit. (Three of the 5 Status B units are cultural.) When the B units are removed from analysis (Table 11b) or combined with A or C units, cultural treatment has very low and statistically insignificant indicator values. *Stability* is also an indicator of B units (all cultural units are stable); it is an indicator of A units when B units are removed.

The last significant indicator is *prescribed fire*. The maximum value of 43% is for Status C units. No additional treatments have significant indicator values.

Analyses with 2 levels of status (b and others)

I performed 3 indicator analyses with only 2 levels of status, with the Status B units removed (Table 11*b*), converted to A units, or converted to C units. Only the first analysis is shown in Table 11*b* because all 3 yielded very similar results. The results are also similar to the indicator analysis with 3 levels of status, except that indicator values are higher in general, in particular for planting (65-66%) and overstory variables (55-65%). Also, some additional treatments have significant indicator values in the 2-level analyses: exclosure, brush release, and, if B units are converted to C, herbicide release. (In 2 of these analyses, exclosure is a better indicator than prescribed fire.) All 3 are indicators of Status A units.

II.F.6. Relationship of individual stages to status

II.F.6.a. Indicator analysis

When the 4 stages and 2 overstory variables (overstory code and density) were tested using indicator analysis, only the 2 overstory variables had significant indicator values, and, as in the treatment indicator analyses, they are indicators of Status C (unpromising) units. When the 4 stages are tested alone, still none has a significant indicator value. However, it is interesting that while propagation, release, and protection (in that order of strength) have indications towards Status A, site preparation has indications towards Status C.

Table 12. Indicator values for each stage at each of the 3 status levels. The indicator values range from zero (no indication) to 100 (perfect indication).

Stage	High status	Med. status	Low status	*p*
Propagation	44	26	21	0.075
Release	33	6	2	0.081
Protection	33	5	1	0.091
Site preparation	32	26	42	0.152

II.F.6.b. Stage abundance by status level

The summary of maximum intensity per stage (and across all stages) by status is shown in Figure 20. The *sum* of intensity results are not shown because they are very similar to the maximum intensity results. The summary of treatment counts by stage is shown in Figure 21. In all cases n=59, the number of treatment units.

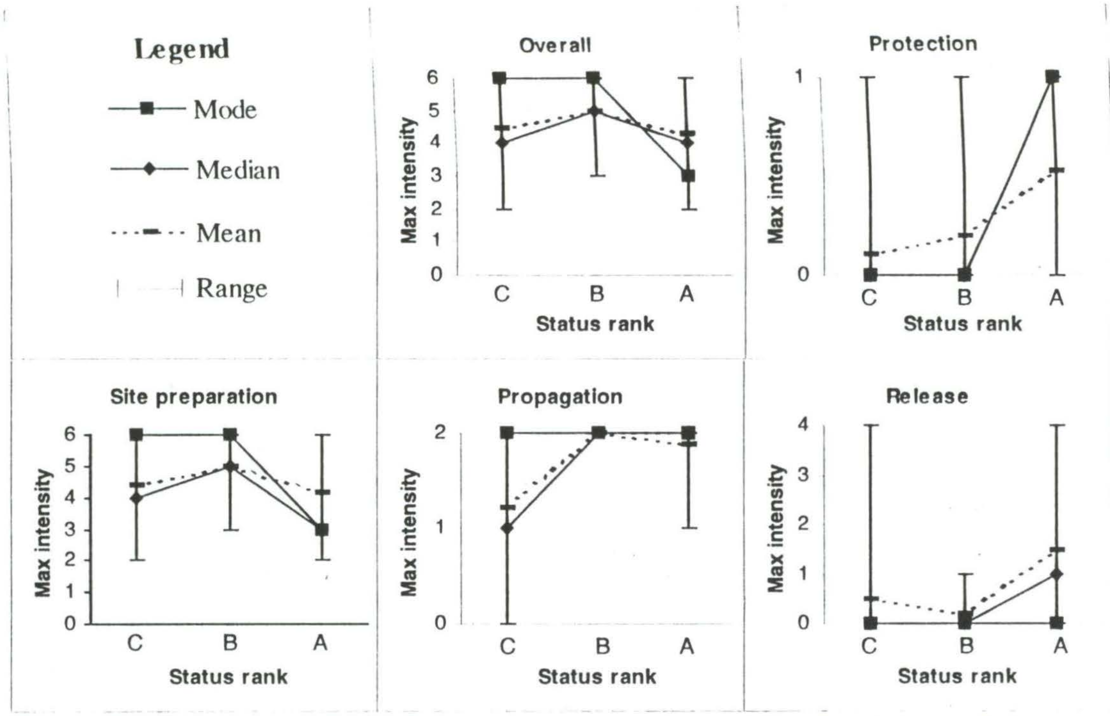

Figure 20. Summary statistics for maximum intensity rankings by status and stage. "Overall" is the maximum intensity across all stages. Note that the bars represent *range* rather than standard error. n = 59 units.

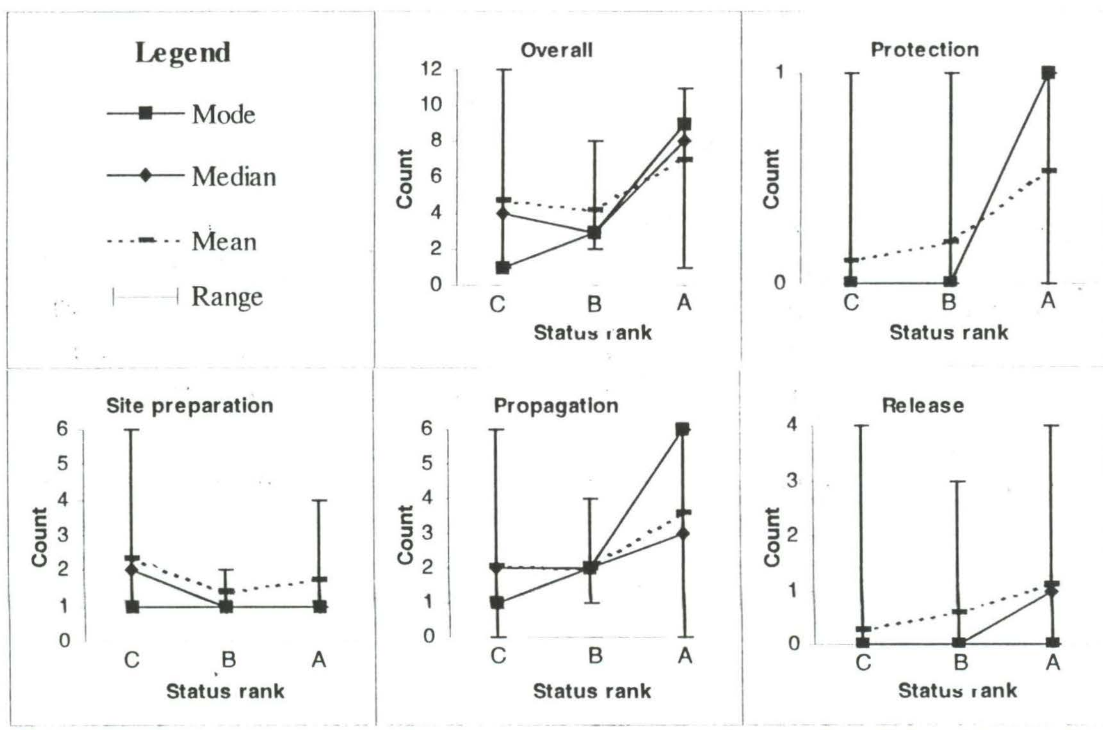

Figure 21. Summary statistics for the count of treatments to each unit by status and stage. "Overall" is a summary of the total number of treatments applied to each unit (*i.e.*, across all stages). Note that the bars represent *range* rather than standard error. n = 59 units.

Across all units, maximum intensity decreases somewhat with increasing status, while the number of treatments increases. This means that promising units tend to have more applications of lower-intensity treatments. Propagation contributes the most to the increase in number of treatments with increasing status (Figure 21) while site preparation contributes most to the decrease in intensity with increasing status (Figure 20). In my ranking system, site preparation intensities range higher than intensities of treatments in other stages (Table 6).

Site preparation: All units had site preparation but, on average, promising units had lower intensity site preparation (Figure 20). They also had slightly fewer site preparation applications, on average (Figure 21).

Propagation: The 2 propagation intensity rankings are 1=seeding and 2=planting. All promising units were artificially propagated. At each status level, most units were planted (Figure 20, mode = 2 = planting), but more promising units were planted than unpromising units (Figure 21).

Protection: Protected units were ranked both promising and unpromising, but more promising units were protected (9 units) than unprotected (8 units). The treatment count and maximum intensity results are the same because the only protection method is fencing, and it is only applied once.

Release: There are 2 possible intensity rankings for release; brush release = 1 and herbicide release = 4. Most units were not released (Figure 20, mode = 0), but more promising units were released than unpromising. The higher average intensity of release to promising units is mostly a result of more brush release (7 promising units; see Figure 19) rather than the higher-intensity herbicide release (5 promising units, 2 of which were also brush released). Of released units, most were released only once (10 of 17 units), but some were released as many as 4 times (Figure 21).

II.F.7. Classification of units by treatments and relation to status

II.F.7.a. Multi-Response Permutation Procedures (MRPP)

This statistical test indicates significant differences in treatment "composition" between promising and unpromising units. That is, there is a difference in treatments performed on A-, B-, and C-ranked units. The result is the same with 2 or 3 levels of status, with every treatment measure, and with stages rather than treatments as the variables; every data file I tested demonstrated a statistically significant multivariate difference among status groups.

This test does not help determine the differences in treatments among status groups, but it lends validity to the following classifications I used to attempt to describe these differences. These other methods do not have associated statistical tests.

II.F.7.b. Cluster analysis

Classifications of different data summaries (counts of treatments, treatment presence, stage presence, and stage intensity, with and without different measures of overstory) result in quite different groupings of units. No classification perfectly divides promising from unpromising units. Classifications based on intensity values were dropped because they do not yield informative classifications. Most other classifications are fairly well related to status, at some level of the hierarchy, particularly those with overstory data included.

A difficulty with this method is that adjacent units tend to get put together, because they have the same treatments except for 1 or 2 "critical" differences.

When overstory data are included, the coarsest grouping of each classification corresponds quite well to a grouping of units by status. In all classifications, the group with mostly unpromising units ("unpromising group") is more *uniform*[8] than the "promising group," and the promising units are more *grouped* than the unpromising units. This result is expected based simply on the difference in total unpromising (37) and promising (17) units. Promising units in the unpromising group are usually *fenced*; usually a scattered overstory has put these units into the unpromising group.

Classifications based on treatment counts (Figure 22) have the best uniformity and grouping. The treatment presence and stage presence classifications (Figure 24) are not as good as treatment count classifications, but they still give reasonable results when overstory density is included as a treatment.

Treatment count data

Of classifications based on treatment count data, the best classification results when **overstory code** is included as a treatment (Figure 22a). 94% of promising units are together in one group, and 89% of unpromising units are in the other ("unpromising") group. The only promising unit in the "unpromising" group is MLEF (plus medium-status CFOF). The coarsest grouping in this classification is related to overstory code, planting, and release: in the promising group all units have an overstory code of 1-4 (no overstory or scattered pine) and most units were

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[8] Uniformity = % of units in Group 1 with Status 1; Grouping = % of units with Status 1 in Group 1.

planted, whereas in the unpromising group all units have an overstory code of 4-9 (scattered or dense overstory), most were not planted, and most were not released.

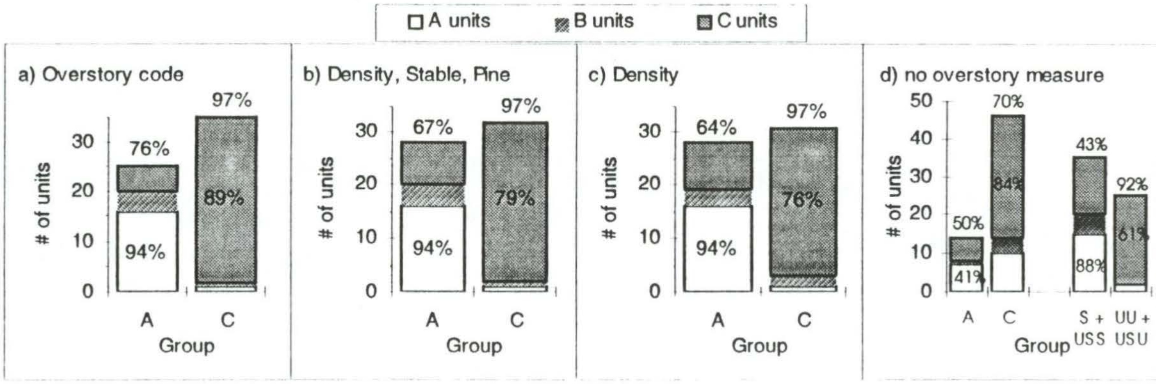

Figure 22. Comparison of the quality of 4 cluster analyses of treatment count data plus the overstory variable(s) listed above each graph (a-d). Each bar represents the units of a coarsest-level A (high status) or C (low status) group and shows the status ranks of the units in the group. The *uniformity* of the group (% of Group "1" with Status "1") is shown above the bar, and the *grouping* of the status level (% of Status "1" in Group "1") is shown inside the bar. Status B units are not included in these percentage values. In part (d) a lower-level grouping (see text and Figure 23) is shown in addition to the top-level groups. Overstory variables are described in the Factors section (p. 56).

The next best treatment count classifications include

- 3 separate overstory variables—**density, stable, and pine**—as treatments (Figure 22b) and
- 1 overstory variable—**density**—as a treatment (Figure 22c).

There is not much difference in the coarsest grouping of these 2 classifications, and the stable and pine variables do not contribute much to the division by status. As with overstory code (Figure 22a), both classifications have only one A unit—MLEF—and 2 B units—CFOF (both classifications) and MIR (overstory density only)—in the C group. The coarsest grouping in these classifications is related to density, planting, and release. In the 3 overstory variable classification, pine is also related, because higher density units are more likely to have pine. Units in the A group have density of 0 or 2 (none or scattered, most with no overstory pine) and all but 1 are planted; the C group units have a density of 2-3 (scattered or dense, most have overstory pine), most are not planted, and most are not released.

Within the A group, most A units are grouped together at the second level in the 3 overstory variable classification (no overstory, no pine), and at the second (no overstory) and fourth (fenced) levels in the overstory density classification.

The classification with **no overstory measure** is not nearly as good at separating A from C units in the first division (Figure 22d). However, a fairly good grouping results at the third level of the hierarchy (Figure 23, Figure 22d, "A + CAA" and "CC + CAC") when the first-level A group is combined with a third-level A group (under the first-level C group, CAA) and the second-level C group (CC) is combined with the third-level C group (CAC). In this way 92% of the units in one group are unpromising (C, with EPE and MLEF as exceptions), while the other group is a mixture (15 A, 5 B, and 15 C) and does not break down in lower levels of the hierarchy. 88% of A units are in this latter group. "A" are all planted, seeded, and cut, "CAA" are all planted, "C" and "CAC" are not planted or released, all "CAC" were burned.

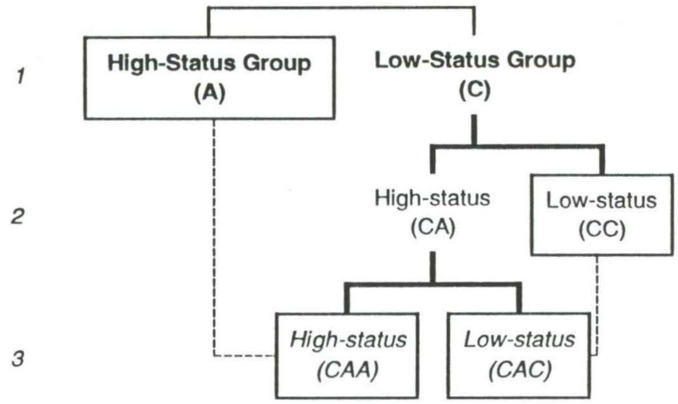

Figure 23. The 3 hierarchy levels used in the classification of treament counts with no overstory data. The dashed lines show the groups lumped in the calculation of uniformity and grouping.

Presence/absence data for treatments and stage

Without overstory data, presence/absence classifications are poor at separating promising from unpromising units (Figure 24d), although promising units do group somewhat at lower levels of the hierarchy.

When an overstory measure is included, there is essentially no difference between the quality of the treatment presence and stage presence classifications. While overstory *code* is the best overstory measure to include with treatment count data, it yields a poor classification when combined with treatment presence (Figure 24c) or stage presence data (not pictured). Instead, these data sets give reasonable classifications when overstory *density* is included as a treatment (Figure 24a,b).

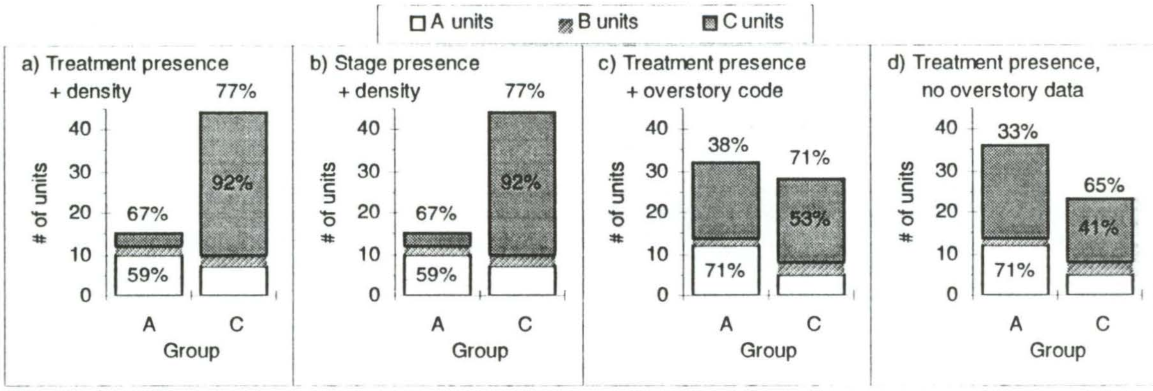

Figure 24. Comparison of the quality of 4 cluster analyses based on presence/absence data of treatments and stages. Each bar represents the units of a coarsest-level A (high status) or C (low status) group and shows the status ranks of the units in the group. The *uniformity* of the group (% of Group "1" with Status "1") is shown above the bar, and the *grouping* of the status level (% of Status "1" in Group "1") is shown inside the bar. Status B units are not included in these percentage values.

These 2 classifications—treatment presence with overstory density (Figure 24a) and stage presence with overstory density (Figure 24b)—are identical at the coarsest grouping, which is based on overstory density alone. Units of the A group have an overstory density of 0 while units of the C group have a density of 2-3. 59% of the A units are in the 0 density group and 92% of C units are in the higher density group. The 3 C units in the 0 density group are JP1U, SLEW, and RP4. The 7 A units in the C group are, except for MLEF, together in a subgroup.

II.F.7.c. Manual classification

The manual classifications which most cleanly reflect pine regeneration status are shown in Figure 25. The simplest classifications first group units by overstory density or planting. These 2 factors are related (see treatment pairs section), because no planting has been attempted under a dense canopy.

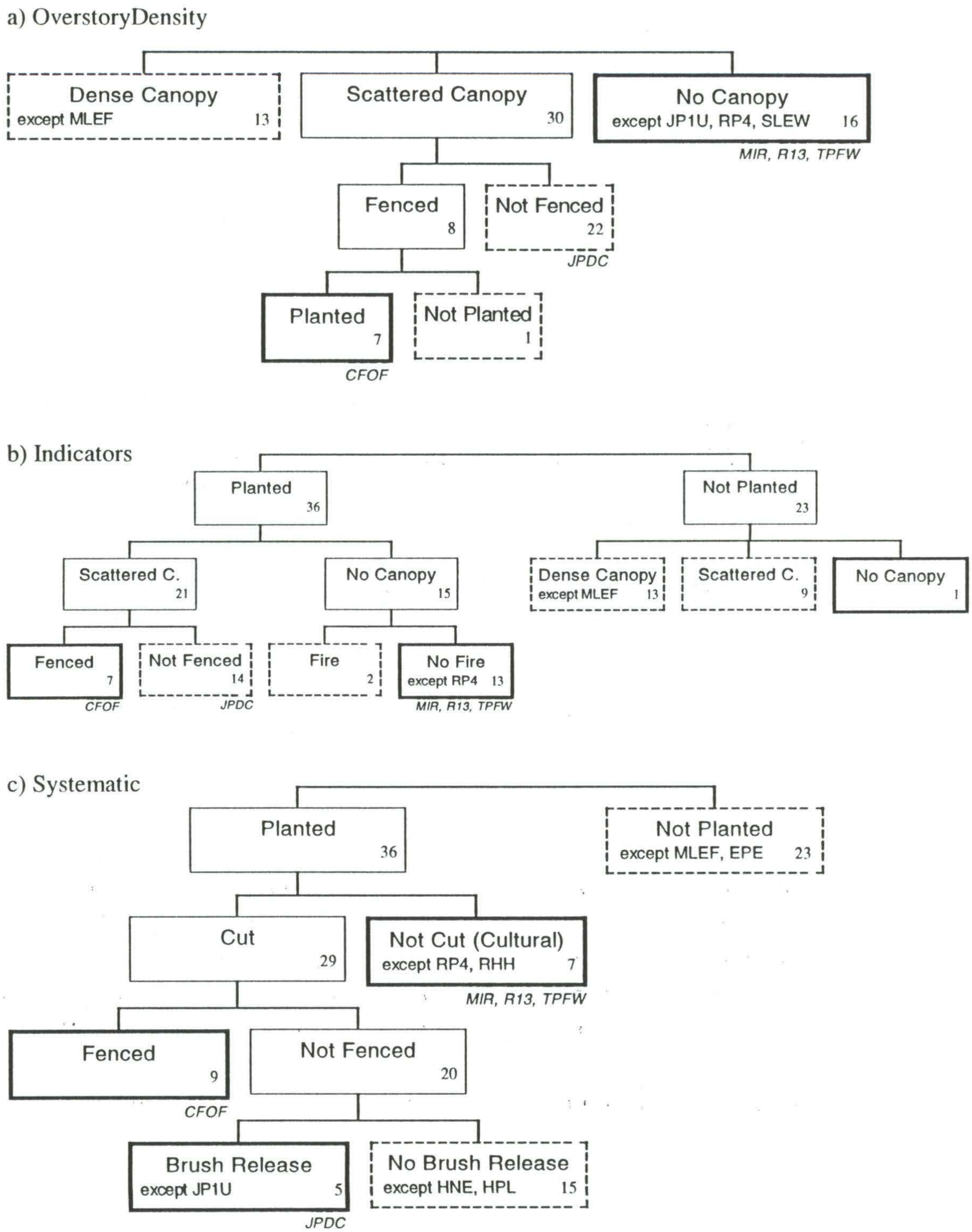

Figure 25. The 3 best manual classifications. The number of units in each group is shown in the bottom right corner. Groups that are primarily Status A have a thick border, and groups that are primarily Status C have a dashed border. Exceptions are listed. The 5 Status B units are included in the counts and listed below the boxes.

a) The classification in Figure 25a first divides the units by **overstory density**. Units with dense canopy and no canopy cannot be meaningfully subdivided further, because:

- none of the dense canopy units is promising, with the notable exception of MLEF (a confounding factor is that none of these has been planted), and
- all but 3 no canopy units are promising (including 3 medium units; most of the no canopy units are planted and unfenced).

Among units with a scattered canopy, none of the **unfenced** units was promising (including 1 medium unit) and all but 1 of the fenced units were promising (including 1 medium unit); the one unpromising fenced unit (WPKF) is the only unit in the group that was not **planted**. Another confounding factor is that all fenced units have pine in the overstory; not all unfenced units do.

b) The classification in Figure 25b divides units by treatments with significant indicator values (Table 11) in the order of indicator strength, *i.e.*, planting, overstory density, prescribed fire, exclosure. I used only the best indicator of overstory condition.

Only 2 units that were not **planted** are promising: EPE and MLEF. Not all planted units were promising, however. **Overstory density** gives a clearer picture, with more promising units under no canopy. (There are no planted units under dense canopy.)

- Under no canopy, 2 of the 3 unpromising units were **burned**[9]. Fencing does not divide the promising from unpromising among planted units with no canopy.
- Under a scattered canopy, fire does not separate promising from unpromising units. However, the next indicator treatment, **exclosure**, divides the units perfectly, *i.e.*, all promising units were fenced and all unpromising units were not (with 1 medium unit in each group). The last indicator treatment, **brush release**, is not as good at dividing the scattered canopy group; however, all but one of the released units are promising, and the few promising unreleased units are all old fields.

c) The classification in Figure 25c divides units systematically by choosing treatments that best divide promising from unpromising units. Overstory variables are not included in this classification. The resulting order of treatments, starting with the treatment that gives the best grouping, is planting, felling, exclosure, and release by brush removal. Only 2 units that were not **planted** are promising: EPE and MLEF.

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[9] But these 2 burned units are likely low status for reasons other than fire: the problem for JP1U is likely deer and for SLEW is likely heavy aspen sprouting after blading.

Among planted units,

- all but 2 of the **uncut** units are promising (including 3 medium units); all of these uncut units are cultural.
- Of planted and **cut** units, all **fenced** units are promising (including 1 medium unit). With 3 exceptions (and 1 medium unit), the unfenced units are promising if released by **brush removal** and unpromising if not.

The last division of unfenced units into brush-released and not brush-released is compounded by overstory density. All but 1 of these brush-released units had no canopy, while all but 3 (including the 2 exceptions) of the unreleased units had a scattered canopy.

Medium-status (B) units

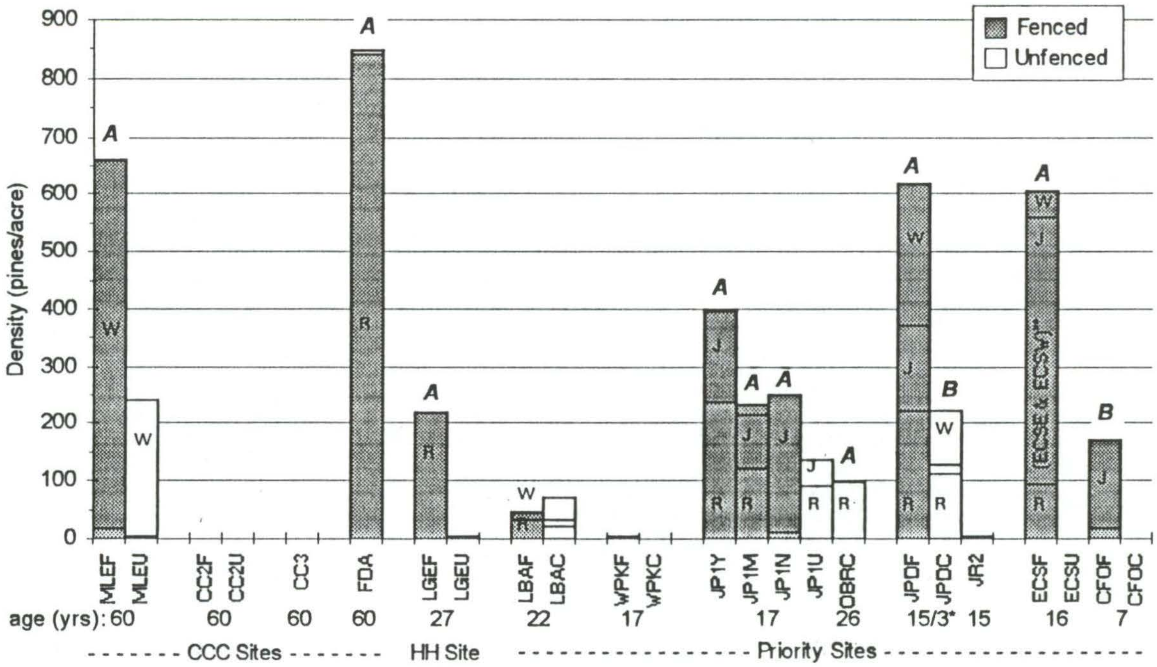
MIR, R13, and TPFW are in the same, A (promising) group in all 3 manual classifications. They are planted cultural units with no canopy and no fire. CFOF is also always in an A group; it is planted and fenced. JPDC is in a C group in 2 of the 3 manual classifications; it is unfenced under a scattered canopy, but it is released, which puts it into the A group in the last classification.

II.G. Intraproject Comparisons (Results and Discussion)

In this section I compare pine regeneration densities of units related by geography or similarity of treatment history. The graphs in Figure 26 show 1995 or 1996 densities for units grouped by a particular treatment. Units of the same supersite are included, even if they did not receive the treatment. Units that fit into more than one category are shown in each.

The text briefly describes the history of each unit (for the full summary of management history of each site, see Chapter 1), why it may have attained its current pine regeneration status, and relates its pine density to the pine densities of related units.

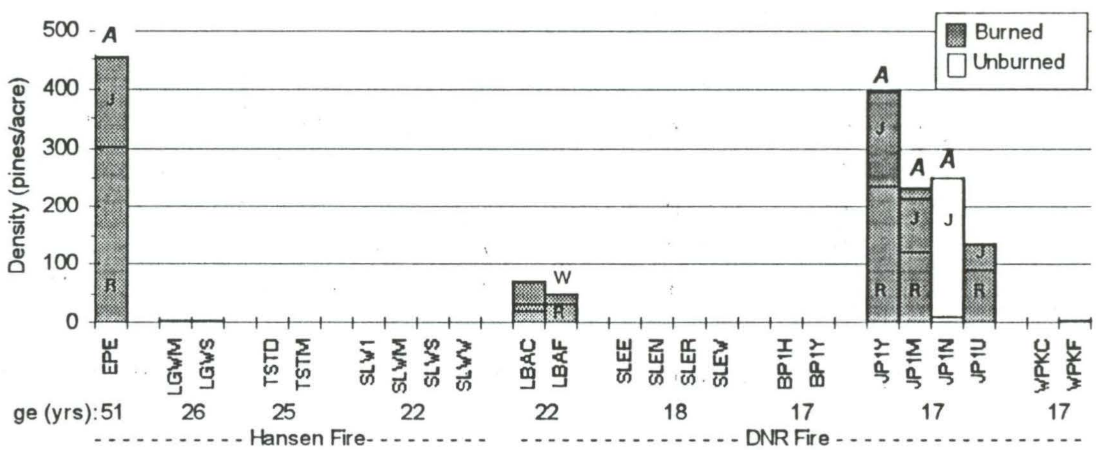
a) Fenced sites



*JPD units were started 15 years ago but the modal pine reproduction age is 3.

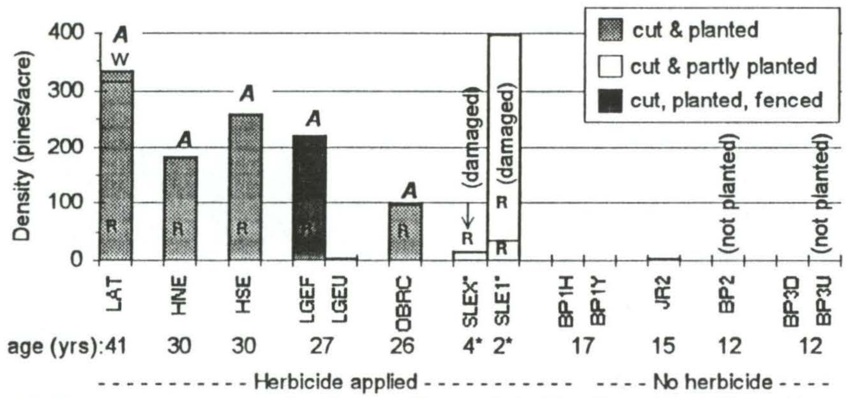
**ECSF is comprised of 2 units (ECSE + ECSW) which were indistinguishable in the field.

b) Burned sites



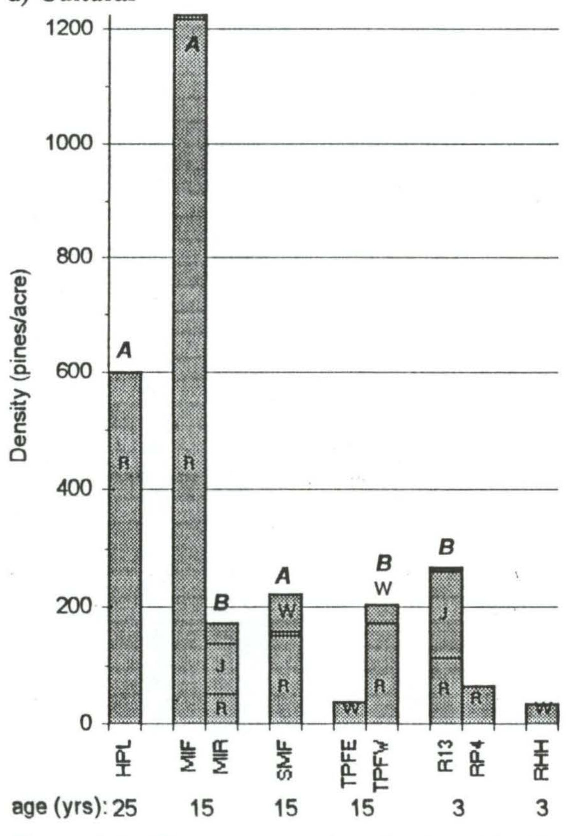
(*figure cont. on next page*)

c) Cut and planted sites



*SLEX and SLE1 are not units, they are "Squaw Lake East Experimental" and "Squaw Lake East I," 2 projects which were later burned over as part of "Squaw Lake East." The SLEX density is calculated from 1971 data (4 years after propagation) from the files of V. Kurmis, and the SLE1 density is the 1974 value (2 years after propagation) from Hansen *et al.* (1974).

d) Cultural



e) Sprayed only

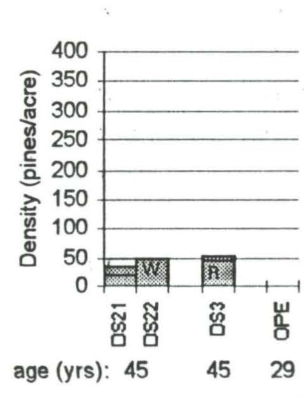


Figure 26. Pine regeneration density of units grouped by treatment: a) fenced, b) burned, c) cut & planted, d) cultural, e) sprayed only. Controls not receiving the treatment are included. Units can belong to more than one group. Pine species are shown, from bottom to top, as (R)ed pine, (J)ack pine, and (W)hite pine. A- and B-status units are indicated. The maximum y-axis value is not the same in all graphs, but the scale is the same and all graphs can be directly compared. The age of each unit is shown under its name.

II.G.1.a. Fenced Sites

There are 11 exclosures around 14 units. Some units are inside the same fence. The exclosures can be grouped into several projects based on date and management.

<u>CCC Reproduction Plots (1937)</u>

MLE (or CC1), CC2, and CC3 were part of the same Civilian Conservation Corps project and were treated similarly (mechanical site preparation and seeding white pine in plots) and fenced at the same time (1937), but they have different overstories (Table 13). FDA was also a CCC project and occurred at about the same time as the others, but the treatments were different and the target species was red pine (and perhaps others).

Table 13. Overstory composition of CCC sites in 1937 (density in trees/acre) from Thoma (1988).

Site	Total pine	RP	WP	JP	Aspen	Birch
MLE	151	144	2	4	5	46
CC2	108	101	4	19	34	56
CC3	1	1	0	0	high	high
FDA*	*none (?)*					

*Not included in Thoma (1988).

Mary Lake Exclosure had (and has) an overstory almost entirely of red pine (Table 13). Inside the fence (**MLEF**), in 1984, there was a pine regeneration density of 659/acre (most >4.3 m tall and >30 years old), while outside (**MLEU**) the regeneration density was 239 pines/acre and pines were stunted (<2.1 m tall) and all less than 20 years old (Steingraber 1989). MLEF has an exceptional pine density among the treatment units; it is 1 of 5 units whose pine density exceeded the ideal density criterion as shown in Figure 12 (p.65). It is the only Status A unit of predominantly white pine.

While the treatments were slightly different inside than outside of the fence, Steingraber (1989) found no difference between the mechanically-treated subplots and the rest of the plot and found no pines originating from the 1937 seedings. Therefore, it is safe to say that the fence is the main effect on the difference in pine density.

It is unclear why the fenced portion is Status A; the unit is an anomaly. It is the only unplanted (and essentially unpropagated) promising unit, and as far as we know, it had no follow up. It is also unusual that brush was not a problem. Circa 1937 Amidon (Ross *et al.* 1970) reported that, "*Corylus* brush is sparce [sic] except in the southeast part where it is dense," perhaps due to deer because, according to Amidon, *Corylus*, *Alnus*, *Salix*, and *Amelanchier* were all severely browsed at that time.

CCC Reproduction Plot 2 (CC2) also had an overstory of red pine, but had a slightly higher density of aspen and birch (Table 13). The fence was removed 3-7 years after the 1937 installation. Neither the fenced nor unfenced portions had any evidence of pine reproduction in 1987 (Thoma 1988).

The reason for the lack of regeneration on the fenced portion is unclear. The fence was removed prematurely, but it is not known if the removal was due to perceived failure of the site. Seedling counts at least 2 growing seasons after seeding (date unknown) indicate virtually no germination, even in treated plots, compared to substantial germination in MLEF (which also had germination before treatment). However, the MLEF saplings that were still alive in 1984 had all germinated more than 10 years after the 1937 treatments (*after* the removal of the CC2 fence).

CCC Reproduction Plot 3 (CC3) had an overstory of primarily aspen and birch (Table 13). The fence was removed 3-7 years after the 1937 installation. There was no evidence of pine reproduction in 1987 (Thoma 1988).

The fence was removed prematurely, but it is not known if the removal was due to perceived failure of the site. (There are no seedling counts after treatment.) The site appears to be quite mesic based on the overstory and the fact that white cedars were planted in one portion. Likely the competition from shrubs, aspen, and birch was too great under these conditions. Furthermore, there was little opportunity for natural seeding.

Forestry Demonstration Area, unlike the other 3 CCC sites, was probably clearcut, was planted, and had some follow-up, including at least one supplemental planting. The fence was likely added as a follow-up. And unlike CC2 and CC3, the fencing was not removed until 1970. Unfortunately, less information is available about the history of this site than is available for the other 3 CCC sites. The area I chose to be a unit **(FDAM)** is the only part with a promising pine density (red pine), 4 out of the 18 acres. Another portion (1 acre) was planted to Scotch pine, another (5 acres) currently has white spruce, and another (2 acres) has scattered spruce with aspen and birch. It is unclear if the latter 2 portions received the same treatments as FDAM. The areas of scattered pine with aspen and birch (5 acres) likely were treated similarly to FDAM. It is possible that the difference in pine survival is related to environmental differences within the site.

FDAM is the unit with the highest density relative to its age, and 1 of 5 units whose pine density exceeded the ideal density criterion as shown in Figure 12 (p.65). While this clearly is one of the highly promising sites, the especially high density is perhaps misleading, considering it is estimated from only the best part of the site. If the other portions were treated in the same way as FDAM, they would be part of the unit and the overall density would be much lower.

Henry Hansen Fenced Site (1970)

Sewage Lagoon East (see also "Cut and planted sites") was cleared of aspen and birch leaving an overstory of scattered pine. It was mechanically site prepared, planted, and chemically released. Follow-up was extensive, with 3 additional plantings and 2 extra releases. Only a small portion was fenced. There is absolutely no regeneration outside the fence (**LGEU**) and excellent results (red pine) inside (**LGEF**, 219 pines/acre). The pines are tall enough that it is safe to remove the fence.

There were very low survival rates (35%) early in the project, even *inside* the fence. The high mortality rate on the site was attributed to deer browsing, but presumably this was not the cause of the early problems inside the fence. Survey results from 1974 shows a high density of browsed and especially girdled seedlings inside the fence; presumably these are rabbit-caused. It seems clear that without the extensive follow-up LGEF would also have been Status C.

"Priority Sites"

All were cut (at different times) leaving a scattered pine overstory, except for 2 Jack Pine 1 units (JP1N and JP1U) with essentially no overstory remaining. All but Centennial Forest, which was fenced in 1991, were fenced in 1988. Old Bemidji Road Area and Jack Pine Restoration #2 are included here (in italics) because they are adjacent to fenced sites.

Lagoon Burn Area (see also "Burned sites") had a denser overstory than the other priority sites. It was cut and burned in 1975 (a summer burn which did not carry), burned twice more, and seeded once in 1981. Follow-up was brush release and the fence installation in 1988, and another brush release and seeding. Inside the fence (**LBAF**) I found only 3 pine seedlings (47/acre). Outside the fence (**LBAC**) I estimated 602 pines/acre, but only 7 total (69 white and red pine/acre) were over a year old, and even those were very young. Both units are Status C.

There are differences between the two units besides the fence: the unfenced portion is on a slope, has a lower overstory density (at least prior to the 1995 blowdown which severely impacted the fenced area), and has a much lower shrub biomass. Bracken fern (*Pteridium aquilinum*) is also very dense inside the fence, and almost absent outside. These differences are plausible explanations for the higher germination rate outside the fence. The hill (outside the fence) is more subject to erosion, and if the duff is washed away a better seedbed is created.

The overstory of both portions is too dense for red pine, and perhaps also for white pine. Deer may be the problem for white pine survival outside the exclosure ("extremely heavy deer browsing" was considered to be the problem before the fence installation), but there is also almost no survival inside the exclosure. Competition from shrubs and bracken seem to be the main problem inside the fence, but there are also open areas with no seedlings. However, some of the open areas were very new, a result of skidding following the blowdown of the year before my survey. There were apparently enough white pine seedlings inside the fence in 1990 (2 years after fence installation) that a planned burn was cancelled, even though brush competition was "severe." The seedlings clearly did not survive.

White Pine Knob (see also "Burned sites") was cut and burned in 1980 and burned and seeded in 1981. The only follow-up was the fence installation. A 1993 burn was scheduled but never took place. There is virtually no reproduction inside (**WPKF**) or outside (**WPKC**) the fence. At the time of the fence installation, there was very little existing regeneration to protect. There is a very high shrub biomass both inside and outside the fence, which probably prevents germination or survival. Furthermore, the fence has not been entirely effective; I could squeeze through the closed gate, and so, it seems, could the deer, because I found deer pellets inside the fence in 1995. The control is quite small, next to the road, and is 30-50% wetland.

Jack Pine 1 was cut in 1980, burned in 1981 (all but JP1N), and planted in 1982. Follow-up was 4 additional plantings, a seeding, a brush release, an herbicide release to most (**JP1Y**, **JP1U**), and the fence (**JP1Y**, **JP1M**, **JP1N**). There are 135 pines/acre (primarily red pine) outside the fence (**JP1U**), but they are all very stunted. Inside the fence there is an overall density of 337 pines/acre (jack pine and red pine); they are tall and healthy, although there are large pine-less patches (with very dense shrub cover) throughout the site. The control is large, and the fence has clearly made a difference. Still, the long survival of pines outside the fence, and inside the fence before it was installed (enough to warrant putting up the fence) is impressive. The extensive follow-up appears to have been rather important.

Within the fenced and burned area, the released portion (JP1Y) had higher red and jack pine densities than the unsprayed portion (JP1M). P. Rundell (personal communication) says that the current shrub-free spots (about the only places with regeneration) are where the brush was sprayed. However there are also openings in the unsprayed area. The burned vs. unburned areas are discussed in the "Burned Sites" section.

The Old Bemidji Road Cut Area (***OBRC***, see also "Cut and planted sites") is adjacent to Jack Pine 1. Although it was never fenced, it is Status A with 98 mature red pine/acre. The planted jack pine did not survive. There was some deer damage (about 30% of red pine seedlings in 1973), but apparently not nearly as much as JP1 sustained. Old Bemidji Road was planted in 1971 while Jack Pine 1 was first planted in 1982; perhaps the deer density was lower at the time of the OBRC planting.

Jack Pine Demonstration Area was cut, planted, and seeded in 1982. Follow-up was an additional seeding and planting (2 plantings inside the fence), 2 brush releases (3 inside the fence), and the fence. Inside the fence (**JPDF**) in 1996 the pine density was 619 pines/acre (all 3 species), compared to 221 pines/acre outside the fence (**JPDC**; enough to make this a Status B unit). The only seedlings in the control were natural white pine and some red pine seedlings from the 1994 planting (2 years before my survey). The control is very small and is next to a road; it did not receive the same treatments as the fenced area.

Jack Pine Restoration 2 (*JR2,* see also "Cut and planted sites"), which apparently had the same treatments as Jack Pine Demonstration until 1983 when it was abandoned, had no pine regeneration in 1996. It received none of the follow-up treatments that Jack Pine Demonstration Area received. However even in 1983 it was considered that Jack Pine Demonstration Area had more promise. However, P. Rundell told me that the Demonstration Area might also have been abandoned if it had not been so visible to the public.

East Contact Station was cut in 1981 and planted and seeded in 1982. Follow-up was 3 additional plantings, an herbicide release in a portion (**ECSE**), and the fence installation in 1988. The fenced area (**ECSE + ECSW = ECSF**) is Status A with 604 pines/acre (primarily jack pine), while I found no regeneration outside the fence (**ECSU**). However, the control is very small and on the edge of the clearing, and I am uncertain that it received all of the treatments applied to the fenced area.

I have lumped the ECSE and ECSW densities because the location of the spray area (ECSE) is unclear. There is no pattern of pine density or condition that can be related to potentially sprayed areas. ECSW does not make a good control anyway, because according to a 1986 survey prior to the release, ECSW had better regeneration than ECSE. Brush does appear to be a current problem; it is quite dense and most pines are in the brush gaps. One area is in especially good shape and the pines are overtopping the hazel, but I have been unable to relate this area to any treatment or site condition.

Centennial Forest is the youngest Priority Site. It was cut in 1990 and mechanically site-prepared, planted, seeded, and fenced in 1991. By 1994 there had been no follow-up. The fenced area (**CFOF**) was Status B with a poorly distributed 170 pines/acre (primarily jack pine);

there are no pines in high-density hazel areas and in the openings they are mostly very clumped. The site will need more planting or seeding and brush control to succeed. The adjacent East Contact Station, which was first propagated in 1982 and fenced in 1988, has done much better. Outside the fence (**CFOC**) I found no regeneration. Unfortunately, this control is very small and is only on the edges of the clearing, and my data sources do not prove that it indeed received the same treatments as the fenced area.

Summary of fenced sites

All fenced sites, with the probable exception of Forestry Demonstration Area, had scattered or dense pine overstories. In all cases but 1 (Lagoon Burn Area), pine regeneration density was higher inside the fence than out. Another exception is Old Bemidji Road Area, an older unfenced Status A unit next to Jack Pine 1. Unfortunately not all controls are true controls. In several cases there was little to no regeneration inside the fence: CC2, CC3, Lagoon Burn Area, and White Pine Knob. Centennial Forest, a young site, is Status B inside the fence.

Status A fenced sites, except for MLEF, were planted and had follow-up. In fact, Mary Lake Exclosure is only 1 of 2 unplanted Status A units. High shrub densities and lack of follow-up seem to be the main problems for pine generation and survival in the seeded exclosures. The cases of Mary Lake Exclosure and Old Bemidji Road Area indicate that timing and location may also be an important factor in the status of these sites.

II.G.1.b. Burned Sites

East Park Entrance (EPE) (RP, JP) is the result of a 1946 wildfire, which probably was more intense than a prescribed fire, but I unfortunately do not have any information about this event, or what happened afterwards. It appears that there was little to no overstory after the fire, and that it was planted[10] (H. Hansen called it a "plantation"). The fire was likely hot enough to create good conditions for pine, and the timing was coincident with a dip in the deer population—the Park was opened to deer hunting the year before the fire, and almost all of the deer were removed. The pine regeneration density is exceptional (457 red and jack pine/acre) for the age of the site; the unit is 1 of 5 units whose pine density exceeded the ideal density criterion as shown in Figure 12 (p.65).

[10] EPE was counted as unplanted in all previous analyses. I later found more evidence to support that it was planted. The discrepancy does not affect overall results.

1970s (Henry Hansen)

Two-Spot Trail Burn (TST) was never cut; half was jack pine forest and half was aspen forest. It was burned once (May 1971) and *possibly* a second time (1974). A summer 1970 attempt never got started. Only a small portion was seeded, and the jack pine seed trees did not produce much (Hansen *et al.* 1974). The May fire hardly got into the aspen half of the site (P. Rundell, pers. comm.), and except in the southeast portion of the jack pine half, it was low intensity (Hansen *et al.* 1974). It did not kill many trees and only top-killed the shrubs, which "vigorously" resprouted. The aspen did not resprout because it was not damaged. In 1996 I found not a single understory pine.

Sewage Lagoon West (LGWM, LGWS) was cut before burning, leaving a scattered pine overstory. It was burned once (spring 1972) and a portion (LGWM) was seeded. The fire was reportedly intense, but it did not expose mineral soil, and the shrubs and hardwoods came back 10 times as dense as before the fire (Hansen *et al.* 1974). Another burn was planned, following an herbicide application, but the site was disked instead (fall). The last record of the site is an estimate of 50,000 white pine seedlings per acre after disking. In 1995 I found only 2 understory pines (in a sandy area). Probably shrub and hardwood resprouting were again a problem, and probably also deer, considering the problems of the adjacent Sewage Lagoon East. There was no follow-up given to this site; much more effort was put into Sewage Lagoon East.

Squaw Lake East (SLEE, SLEN, SLER, SLEW). Part of this area had already been treated by Henry Hansen (without the use of fire), but that effort had failed (see "Cut & planted sites"). The entire site was cut at different times before burning, leaving a scattered hardwood overstory. The site was burned twice (fall 1975 and fall 1978), seeded afterwards, and planted several years later. Apparently there was no follow-up. According to the manager the first fire was "incomplete," except in SLEW where it was "fairly complete"; there is no information about the second fire. I think shrub and aspen sprouts were a big problem, as well as deer. These were the problems cited by Hansen for the failure of the pre-fire site treatments.

Squaw Lake West (SLWM, SLW1, SLWS, SLWW) was cut before burning, leaving an overstory of scattered and clumped hardwoods and pines. It was burned twice (spring 1975 and fall 1978). The entire site was seeded after the first fire. Small portions were seeded and planted several years after the second fire, and one of these areas was mechanically scalped and planted a second time. In 1995 I found not a single understory pine.

There was not enough follow-up to this site. The first fire was intense only in the jack pine area and was patchy in the north half; afterwards there was vigorous resprouting of shrubs and aspen in the cut portions (Patterson 1978). I have no information on the second fire, but there was either little shrub and hardwood kill or dense resprouting, considering the extremely high shrub and hardwood density I encountered in 1995. Most areas had too dense an overstory and were not planted, but even the small open areas and planted areas have no regeneration. Patterson (1975) says, "the steeper slopes...hold the greatest promise for...establishing pine. The more level land on the northeast 1/3 of the area originally appears to have contained large, scattered white pine with a hardwood understory, and it is unlikely that red pine regeneration can be secured on the heavier soils there." I do not have information about the possibility of deer problems.

Late 1970s, early 1980s (Dept. of Natural Resources)

Lagoon Burn Area (LBAF, LBAC) was cut, leaving dense pine, before burning. It was burned 3 times (fall 1975, fall 1979, and spring 1981) and seeded after the last. Follow-up was started 7 years later with a brush removal and exclosure installation. Another brush removal and a seeding occurred 2 years afterwards. There is very little pine survival on this site.

There was no control for the fires. The first fire "did not burn down to mineral soil in most of the area" (Minnesota DNR 1975), and there is no information about the others. P. Rundell attributed the failure of the 1981 seeding to "extremely heavy deer browsing." In 1986 (before fence installation), a hazel density of 3,875 stems/acre was recorded. A burn was planned for 1991, but it was cancelled: "Severe brush competition throughout but white pine regeneration is occurring and to the point where we have cancelled the planned burn" (Techniques Subcommittee 1992). An overstory that is too dense, competition, and deer outside the fence appear to be the main problems for this site, as explained in the "Fenced sites" section above. The fires clearly were not adequate to prevent these problems.

Big Pine 1 (burned portion is **BP1H**) was cut, leaving an overstory of scattered pine and hardwoods, before burning. It was also herbicided, probably also before burning. It was burned twice (fall 1979 and sometime in 1980) and seeded afterwards; some portions were planted. In 1984 the site was redone with furrowing and planting (no fire; this part of the history is discussed in the "Cut and planted section"). **BP1Y** was not intended to be a control; it was cut but received no other treatment until BP1H was redone.

According to P. Rundell the first fire was "spotty" and the second was a "very good burn." He says that deer ate all the seedlings. Furthermore, most of the site was too wet for pines; a considerable portion was too wet even to be furrowed. The year they chose the site was a dry year. Hardwood and shrubs were extremely dense throughout most of the site in 1995.

Jack Pine 1 (JP1Y, JP1M, JP1N, JP1U) was cut, leaving a scattered pine overstory, before burning. Most of the site (all but JP1N) was burned once (spring 1981) followed by a planting of the entire site. Follow-up was multiple seedings and plantings, a brush release, an herbicide release to portions (JP1Y, JP1U), and the exclosure.

According to the manager, the fire was "fairly complete...and hot enough to burn off vegetation at ground level. Too much frost to kill." The fire may have made a difference for red pine (there is virtually no red pine in JP1N), but JP1N is not a good control: all the jack pine slash (with cones) was piled there (Tucker 1981), providing an excess of seed (and subsequently a very high jack pine seedling density) and perhaps better soil scarification. The fire was hot but not enough to kill shrubs and hardwoods. It appears that it is the planting, fence, and extensive follow-up that has made this the burned site with the best regeneration.

White Pine Knob (WPKF, WPKC) was cut, leaving a scattered pine overstory, before burning. It was burned twice (1980 and spring 1981) and seeded afterwards. The only follow-up was the exclosure installation 7 years later. There was apparently some germination but no survival from the seeding. There is no information about the first fire; the second "consumed brush and old deadfalls leaving a good seedbed" (Minn. Parks & Recreation Interpretive Services. n.d.*b*). There were almost no pine seedlings in 1995. Shrub density and deer are probably the main problems, as described in the "Fenced sites" section above.

<u>Summary of burned sites</u>

Of the 9 burned sites (21 units), only East Park Entrance and Jack Pine 1 (inside the fence) were Status A. Both have both jack and red pine. Unfortunately very little is known about East Park Entrance. Jack Pine 1 is also the only site with a control for burning, but it is not a true control. Three burned sites were fully planted (JP1, SLE, probably EPE) and 2 were planted only in small portions, and 3 burned sites were fenced (JP1, LBA, WPK). Jack Pine 1 is the only burned site which was both planted and fenced, and East Park Entrance (presumably planted) developed at a time of very low deer density; planting and minimal deer damage are likely the main reason for the higher status of these units. Jack Pine 1 also had the most follow-up of any of the burned sites. It is not known if there was any follow-up to EPE. Most sites had 2 fires, but JP1 had only one. It is unclear if the fire had any effect on regeneration because the control is not a true control.

II.G.1.c. Cut and planted (no fire, no fence)

With herbicide (Henry Hansen sites)

These Henry Hansen sites were all treated similarly: cut, sprayed, and planted. Some had additional treatments, such as an extra spraying before felling or mechanical site preparation. Lake Alice Trail and Henry Hansen Northeast and Southeast were cleared of all trees (mostly aspen and birch) while scattered trees were left on the other sites.

Lake Alice Trail (LAT) was sprayed, cut, and sprayed again in 1956, then planted with red and jack pine in 1957. In 1958 there were 15,000 aspen suckers/acre. The follow-up of 2 herbicide releases and 1 brush (aspen) removal was clearly important. The 334 pines/acre in 1996 were almost entirely red pine, plus some (natural) white pine; the jack pine did not survive. In 1971 the natural white pine were heavily browsed, and browsing is perhaps the cause of jack pine failure. Red pine appears to be much less preferable to deer than the other 2 pine species (Orke 1966, Rogers *et al.* 1981).

Henry Hansen Northeast (HNE) was sprayed 2 years before felling, sprayed again and mechanically site prepared just after felling in 1969, and planted with red pine in 1970. Follow-up was 3 additional plantings and 1 herbicide release. This site received more follow-up than HSE, but it had a lower pine density in 1995 (181 red pine/acre on HNE vs. 256 red pine/acre on HSE). It likely needed additional follow-up due to site-specific conditions such as deer density and soil type. HNE had a higher pre-cutting aspen density (Duane Hanson, pers. comm.).

Henry Hansen Southeast (HSE) was sprayed 2 years before felling, sprayed again and mechanically site prepared just after felling in 1969, and planted with red pine in 1970. Follow-up was 2 additional plantings and 1 brush removal. See HNE for more information.

Sewage Lagoon East (LGEF, LGEU, see also "Fenced sites") was cut, mechanically site prepared, and planted in 1970. Only a small portion was fenced, and this was the only part with pines in 1995 (219 red pine/acre inside the fence and only 1 red pine seedling outside). Follow-up was herbicide release in a small area in 1970 followed by a release of the whole site the next year. The first planting was considered to have failed, and the entire site was replanted and released in 1972. This was followed by another planting (to fill in gaps) and herbicide release. Again the site was considered to have failed and another full replanting was done in 1974. Apparently nothing was done after the 1974 planting. This, too, failed, because virtually no regeneration was found outside the fence in 1995. It appears that damage by deer was too strong.

Squaw Lake East (SLEE, SLEW, see also "Burned sites") was 2 separate projects before burning: 1) "Squaw Lake East Experimental" (the SLEW portion) was sprayed after cutting in

1967 and seeded and planted with red pine in subplots in 1969; 2) "Squaw Lake East I" was cut, mechanically site prepared, planted red and jack pine, and herbicide released in 1972. Only these 2 projects are considered here. Both were considered failures; from the data of the last survey of each prior to the fire I calculate densities of 13 and 36 undamaged red pines/acre for the Experimental (1971) and East I (1974) sites, respectively. Competition from aspen sprouts and herbivory by deer and hare were cited as the problems by Hansen *et al.* (1974).

No herbicide

Old Bemidji Road Area–Cut (OBRC) (see also "Fenced sites" where this site is compared to Jack Pine 1) was cut of jack pine and aspen, mechanically site prepared, and planted with red and jack pine in 1971. Follow-up was 2 additional plantings and 1 brush removal. It is Status A with 98 mature red pines/acre. As with Lake Alice Trail, the jack pine did not survive. The density of pines is highest close to the road; in the interior, the high-status is a bit more questionable. Deer were apparently not a big problem for the red pine but they were present and may have been the cause of jack pine failure. Before felling there were only 6.6 cords of aspen (compared to 57.5 cords of jack pine), and this low aspen abundance may be why only the 1 release was needed.

Big Pine 1–Unburned (BP1Y) was cut in pieces between 1976 and 1981. In 1984 it was mechanically site prepared and seeded. Follow-up was 2 plantings. **BP1H** was treated the same way except that prior to the 1984 treatments it was sprayed, burned, seeded, and planted (see "Burned sites"); the subsite was redone due to failure after those treatments. Neither subsite had any pine regeneration in 1995. P. Rundell attributes the problem to deer and rabbit browsing. The site is probably also too wet for pines. At least in 1995 the shrub and hardwood density was very high.

Big Pine 2 (BP2) failed because the project was abandoned. Nothing was done besides cutting aspen and birch. It was not planted, though the original intention was to do so.

Big Pine 3 was cut and furrowed in 1984 and planted in 1986. A portion (**BP3U**) was not furrowed or planted because it was too wet, and it is not surprising that it is Status C. However the planted unit (**BP3D**) also had no pine regeneration in 1995. It is likely that this unit was also too wet for pines. Perhaps more important was browsing by deer. P. Rundell says that because they saw deer tracks going up the furrows, finding all the seedlings, 1986 was the last year of planting in rows. In 1995 the shrub and hardwood density was very high.

Summary of cut and planted sites

Of the 14 "cut and planted" units (including 2 not planted), 5 are Status A (LAT, HNE, HSE, LGEF, OBRC). All are almost entirely red pine, even though 2 (LAT and OBRC) were also planted with jack pine. Follow-up (replacement of seedlings and competition control) appears to be the primary reason for the promising status of these sites, but it also appears that no amount of follow-up is enough for some sites. LGEU received considerable follow-up, but only the fenced portion had any surviving pine regeneration. While the unfenced Status A units in this group sustained damage by deer, it seems that the pressure was not as intense as on the Status C units. According to Hansen & Kurmis (1972), deer damage was less of a problem for HNE and HSE than for LGE and the adjacent LGW. LAT, OBRC, HNE, and HSE are in the east of the Park, where deer densities are presumably lower (P. Rundell, personal communication). On LAT and OBRC deer may have caused the mortality of jack pine while leaving the red pine relatively undamaged. In addition to location, timing may have been an important factor. For example, weather conditions were more favorable during planting of HNE and HSE compared to Lagoon sites (Hansen & Kurmis 1972).

II.G.1.d. Herbicide only (H.H. stimulating regeneration)

Nothing was done to these sites besides spraying with first-generation herbicides. All had dense overstories of pine and hardwoods and little to no existing pine regeneration. The Demonstration Spray sites were treated in 1952, for the explicit purpose of stimulating pine regeneration. Old Park Entrance was treated in 1967. Because it was grouped with the Northeast (HNE), Southeast (HSE), and Squaw Lake East I sites in H. Hansen's records, OPE was probably intended to be treated similarly. If so, those additional treatments were never carried out. Demonstration Spray #1 is not a unit because I could not find it in the field.

Demonstration Spray Number 2 (DS21, DS22) had an overstory of pine with some aspen and birch. The spraying, which according to H. Hansen was effective at damaging the brush, did not achieve the goal of creating a new pine stand: the reproduction densities of the 2 units were 31 (DS21, along a road) and 49 (DS22, a 1-acre plot) pines/acre in 1996. Only white pine was in the plot, but the unit along the road, which receives more light, also had some red pine. Furthermore, there was no visible difference in regeneration between the sprayed areas and adjacent untreated areas; it appears that the spraying did not increase regeneration above a "background" level in the area.

Demonstration Spray Number 3 (DS3) had an overstory of aspen and birch with some pine. The spraying did not achieve the goal of creating a new pine stand: the reproduction density was 53 pines/acre in 1996. Oddly, most of this reproduction was red pine. Furthermore, there was no visible difference in regeneration between the sprayed areas and adjacent untreated areas; it appears that the spraying did not increase regeneration above a "background" level in the area.

Old Park Entrance (OPE) had an overstory of pine and hardwoods. Shrubs were sprayed with 2,4-D under a red pine overstory in July 67. Unlike the demonstration sites, I could see a difference between the sprayed area and adjacent untreated areas. However these effects were visible only on shrubs, and no pine regeneration was present.

<u>Summary of herbicide only sites</u>

Spraying first-generation herbicides under a tree canopy, without other treatments, was not an effective stimulant to pine regeneration.

II.G.1.e. Cultural Sites

All cultural units but MIR (an old road) are old fields, cultivated by farmers (or others) in the past. Headwater's Parking Lot is not considered a "cultural" unit for analysis, because the original site-clearing activity had a natural resource management rather than cultural purpose. It is included here because by the time it was planted the conditions were essentially those of an old field.

Most cultural sites were only planted. Before planting most were sod with little tree or shrub cover.

<u>Older plantings</u>

Headwaters Parking Lot (HPL) is not technically an old field (it was probably not cultivated), but it was considered to be one at the time of planting. It is unclear what conditions or unrecorded treatments may have created this condition. There are still very few shrubs and hardwoods at the site. The original cutting and natural seeding was apparently a failure (if, indeed, pine restoration was what was intended), but the planting 18 years later (1972) was very successful. In fact, it is one of 5 units with a density (600 red pine/acre) exceeding the ideal density criterion shown in Figure 12 (p.65). Follow-up was an additional planting 14 years later. Deer were apparently not a problem. Perhaps the site conditions have prevented invasion by shrubs and hardwoods, but it would be interesting to know if any additional treatments occurred.

Miller's Field (MIF) and **Miller's Old Road (MIR)** are adjacent units that were planted with "mixed pines" in 1982. The field (MIF) had 2 or 3 follow-up plantings, but the road (MIR) had only an additional seeding. Pines on the road suffered extensive damage by deer, while the old field pines were mostly untouched (Paul Rundell, personal communication). Both units had pines in 1996, but the difference in density, height, and condition is astounding. There are 1,225 red pine/acre on MIF, most very healthy and >2 m tall, while the MIR density is 172 pines/acre (all 3 species), all <0.5 m tall and browsed. At least 35% of the MIR seedlings were less than 15 years old (the age of seedlings from the original planting). The MIF results are excellent even among all units; it is one of 5 units whose density and condition exceeded the ideal density criterion shown in Figure 12 (p.65). However, if all 3 species were truly planted, jack and white pine had virtually no survival.

The likely explanation for the difference in survival and condition between the units is that the road is more protected for deer, and it also easier for them to follow along and find seedlings (which, according to P. Rundell, they did while the seedlings were going into the ground). Unlike the old field, the road essentially has an overstory from the hardwood forest lining the road, and it is being invaded by hardwood trees and shrubs, probably because the forest edge is so much closer. The follow-up, done to MIF but not MIR, also likely made a difference.

Sawmill Field (SMF) was scalped before the second planting (1984); deer ate everything after the first planting (1982). According to the manager's notes, only spruce survived the second planting, but in 1996 there were red pine with a density of about 300 red pine/acre (and no spruce) in the south half. There were no red pine in the north half. So it appears that there is more to learn about what happened to this site. There were also some natural white pine of a variety of ages. There were no pines at all in valley between the 2 halves; it could be that deer prefer the valley, that the conditions are too moist, or that this is where they removed transplants.

Trading Post Field is divided into an old campground section with a scattered overstory (**TPFE**) and an old field section (**TPFW**). The old campground also has a higher shrub density. The old field was mechanically site prepared and planted, but it is unclear if the old campground had either of these treatments. There was apparently no follow-up. It is not surprising that the old field had a higher 1996 pine density (204 pines/acre, primarily red pine) than the campground (38 white pine/acre, all <5 years old), considering the difference in overstory and shrub density (and especially if the campground was not even planted with pine). The old field had red pine and white pine while the campground had only white pine; none of the white pine on either unit was more than 5 years old. The old field is only a Status B unit, however, because the pines are highly clumped. Contrary to the manager's notes from 1988, in 1996 only some pines showed evidence of browsing by deer and they were alive and growing. Perhaps the site was replanted?

1994 plantings

These sites were all planted during a dry period, and the jack pine were planted too late after lifting. Many jack pine died immediately. This level of detail is not available for most other units, but problems such as these could have caused some of the difficulties experienced by other units. It is difficult to predict future pine abundance for these sites because they are so young. Red Pine 13 and 4 are nearly adjacent.

Red Pine 13 (R13) is a very open site with only some widely spaced clumps of older trees clumps. These older trees are mostly jack and red pines that are probably natural. They are included in the 1996 pine regeneration density for this site. The grass is very dense and tall in most portions of the site, but the biggest problem appears to have been pocket gophers. Deer do not appear to be a significant problem (field observation), probably because the site a large open area and located at the east edge of the Park where deer densities are reportedly lower (P. Rundell, pers. comm.). There is a density of 268 jack and red pines/acre, and this is a young site. There is some promise for this site if it receives plenty of follow-up.

Red Pine 4 (R4) is a less open site than Red Pine 13. It is smaller and there are more hardwood trees and shrubs. There is also a small amount of older natural pine regeneration. There is a much lower density of surviving pines (65 red pine/acre, no jack pine) than on R13, and it would need at least a full replanting to have a chance of becoming into a pine forest. The grass is less dense than R13 in most of this site, so it is more the overstory that is the problem. Pocket gophers are also a problem at this site, and there may be somewhat more deer damage because this site is more protected.

Roy Hemrick Homesite (RHH) has a relatively (for an old field) dense overstory of hardwood trees and shrubs. Its 1996 density, 35 white pine/acre, all browsed, is the lowest of all cultural units.

Summary of cultural sites

Cultural sites typically do not have the problem of shrub competition as do felled sites, but they can have some unique problems, such as pocket gopher damage. But deer damage and shrub and overstory density appear to be the most important factors in determining regeneration results among cultural units. It is difficult to compare the 1994 sites to the other cultural sites because they are so young. However, even in these sites overstory density appears to make a difference.

Deer and overstory are compounding factors due to the need of deer for shelter. The large open fields (HPL, MIF, and R13) have had less deer damage than smaller, more protected sites

(MIR, TPFE, RP4, and RHH). As with cut and planted sites, most of the pine regeneration of cultural sites has been red pine, the pine least preferred by deer. Jack pine, most younger than 5 years old, are present on MIR and R13, and white pine are present in small amounts on SMF, TPFE, TPFW, and RHH.

II.H. Discussion

II.H.1. Factors affecting pine regeneration

In the past, natural regeneration of pine stands in Itasca was not a certain thing. Not every catastrophic fire resulted in a pine stand (Frissell 1971) and most blowdowns did not result in pines reaching the canopy (Webb 1986). The role of catastrophic disturbance by insects, disease, or other means is unknown (Frissell 1971). The landscape of Itasca was and is a mosaic of vegetation types (Frissell 1971) and the pattern of this mosaic changed over time due to fire patterns and climate change (Clark 1988).

The conditions for the establishment of a pine stand, especially for jack pine and red pine, are quite rigorous, requiring a combination of conditions before, during, and after fire. Factors affecting pine regeneration work at multiple spatial and temporal scales and include:

Site characteristics:

- location (including proximity to roads, conifer cover),
- size and pattern of disturbance,
- history of the site (in terms of disturbance, vegetation, and human activities),
- soil conditions,
- condition of the forest floor (rocks, logs, slash, litter, duff, etc.),
- topography (slope, aspect, topographic position, etc.),
- existing plant community, and
- existing animal community.

Temporal factors:

- changing weather and climate,
- disturbances such as fire and wind,
- population size and health of herbivores (deer, rabbits, gophers, small mammals, insects),
- population size and health of pine granivores (birds and small mammals),
- population size and health of plant competitors and existing pines,

- pine seed crops,
- pine diseases,
- presence of seed and rhizomes of plant competitors, and
- genetic variation in populations of pine or their competitors or herbivores.

The conditions needed for pine establishment did occur, and our current pine forests are the result. But clearly there is a large element of chance in the establishment of a pine forest. A manager cannot control all these factors, especially with limited resources, and therefore cannot expect to be successful in every attempt to grow pines.

Many of these factors have changed significantly in the past century. The effect of humans on the landscape increased dramatically with activities such as logging, land clearing, and near elimination of predators. Some of these changes are discussed below.

The effects of recent climate change are also likely important, but more difficult to ascertain. In certain decades or centuries changes in the mosaic favored some community types over others. Vegetation change was particularly frequent in the Itasca area because it is located on a transition zone between 3 biomes (deciduous forest, coniferous forest, and prairie) and because much of the patchwork is made up of early- to mid-successional types perpetuated by major disturbances highly affected by climate. As a result, a small change in climate can have large impacts on the vegetation.

The vegetation as recorded by early white visitors is only a snapshot in time. Paleoecological evidence tells us that as recently as 2,000 years ago the Park was mixed hardwood forest (Clark 1990). Since then the climate has changed variously from cool and moist to warm and dry, with major impacts on fire frequency and vegetation. This century has been warmer and drier conditions and the early- to mid-century conditions appear to be unprecedented during the 2000 years (Clark 1988). It is difficult to predict the changes in fire regime and vegetation that might have occurred this century without fire suppression or other changes in human activities. Clark (1988) modeled a 25% increase in average fire frequency this century, with a possible increase in pine, based on the climate-fire relationship in the past 750 years.

II.H.2. Artificial regeneration problems as revealed through significant treatments

Managers may affect pine regeneration through site selection, treatment applications, and monitoring and follow-up. In this section I discuss the effects of treatments and follow-up on status.

The timing of treatment applications, relative to each other and to conditions and events such as weather, deer densities, and human activities, is likely quite important but is mostly unknown. Unknown details of the application of treatments, such as the method of logging, time between logging and propagation, and intensity (*e.g.*, amount planted, amount of release, intensity of fire) may also be very important.

Based on the statistically significant results of contingency tables and indicator analyses comparing individual treatments and status, the following treatments are beneficial to the status of a unit:

- planting,
- exclosure, and
- brush removal (release);

and the following treatments are detrimental to status:

- overstory (whatever the measure used) and
- prescribed fire.

Cluster analysis and manual classification have similar results. Cluster analysis shows a relationship of overstory to Status C and planting and release to Status A. The manual classification shows that Status A units with a scattered canopy are planted and fenced. The status of no planting with no canopy has not been thoroughly tested; EPE is the only unit with no canopy that was not planted. The usefulness of brush release as a "substitute" for fencing (see manual classification c, Figure 25c) is unknown because the factor is compounded by overstory density.

These factors and their combination with other treatments are considered below. No one treatment guarantees a high or low status. A combination of treatments and appropriate site conditions, plus some luck, is needed. Non-significant treatments are considered in the sections of related significant treatments: cultural and felling are considered under "overstory," seeding is considered under "planting," herbicide release is discussed under "brush release." Mechanical site preparation, though not significant, has its own section. Site preparation by herbicide, brush release, or blading is not considered because these treatments were so infrequently applied.

Higher treatment intensities of propagation, protection, and release (see Stage section) correspond to Status A, but are not statistically significant. In particular, it appears that multiple applications of lower intensity treatments are important. Site preparation showed the opposite trend. Of site preparation treatments, fire (intensity = 2) and mechanical site preparation (intensity = 6) were detrimental (described below), but the others were not—brush removal (1), felling (3), herbicide (4), cultural (5).

The relative importance of propagation, protection, and release over site preparation points to the importance of follow-up to pine regeneration. Some Status A units had little to no pine regeneration after the first 2-3 plantings, and without follow-up would have most certainly been Status C.

II.H.2.a. Beneficial treatments

Planting

Planting shows up as important to high status in all analyses. All but 2 promising units (91%) were planted, but planting alone is not enough: only 56% of planted units were promising. Fourteen planted units had no canopy; 3 of these were unpromising, and deer can be considered the primary problem for 1 (JP1U). Conversely, 6 of 22 planted units under a scattered canopy were promising, and all 6 were fenced. (No dense canopy units were planted.) Therefore, deer appear to be more of a problem under a canopy than in the open.

The alternatives to planting are direct seeding and no artificial propagation. While *direct seeding* is not a significant treatment, it does show indication towards Status C units. Fifteen units were direct seeded but not planted, and only 2 (13%) were promising. Only 29% of seeded and planted units were promising, whereas 60% of planted but not seeded units were promising. However, these data do not mean that seeding alone will never work, nor that seeding lowers the chance of success of a planting. Rather, seeding is positively associated with canopy: all but 4 seeded units (89%) had a canopy. Two of these were promising—one planted, the other not. In fact, 5 of the 6 promising units under a scattered canopy were seeded in addition to planted.

There are 8 *unpropagated units* and none was promising. Natural seeding was relied upon for 4 of these units (DS21, DS22, DS2, and LGWS), and the other 4 appear to have been abandoned (BP2, OPE, BP1U, and TPFE). Natural seeding was also relied upon to supplement artificial propagation and has been the source for some existing pines, but it has not led to high status when used without artificial supplementation.

Planted seedlings are 2 - 3 years old and have bypassed, in controlled nursery conditions, problems that can occur during that time period. Potential problems limited to, or more problematic during, this early period of the pine life cycle include:

- low seed supply (which can be surmounted by direct seeding),

- seed mortality (by rodent or bird granivory or fungal infection),
- low germination rates (due to, for example, improper microsites or weather),
- vulnerability to drought and other unfavorable weather,
- shading by short plants and leaf litter (Hansen *et al.* 1974),
- browsing or girdling by small mammals and insects,
- vulnerability to disease, and
- decreased resistance to browsing and disease.

There are perhaps other forces that kill such young seedlings. I see 1-year-old white pine very commonly throughout the Park, but rarely an older natural white pine. They simply disappear.

I do not list deer browsing as especially problematic for young seedlings because in winter, when deer eat pines, the young seedlings tend to stay buried by snow. According to Ross *et al.* 1970, seedlings in Itasca less than 6 inches (0.15 cm)—about 1-3 years old—are rarely browsed by deer because deer rarely dig so far into the snow. Furthermore, white pine seedlings less than 3 years old appear to be less palatable than older seedlings (Hay & Rennie 1989). However when young seedlings do get browsed (particularly when deer are starving or during times of low snow depth, factors which tend to coincide in early spring), they are more likely to be killed than older seedlings with more biomass.

Transplanting stress is sometimes a problem for planted seedlings, but it appears to be outweighed by the benefits. Another disadvantage of planting is that it is expensive and labor intensive. As a result, planted sites tend to be better cared for than unplanted sites: 78% of planted units had follow-up, compared to 35% of unplanted units. Such better care is a compounding factor in the apparent benefits of planting.

Exclosure

Fencing shows up as an important treatment in all analyses. It was not a factor that drove the grouping of units in cluster analyses, but in most cluster analyses, promising units in unpromising groups tended to be fenced. 71% of fenced units are promising but only 45% of promising units were fenced. Therefore, while fencing has been beneficial, it has not been a requirement for pine regeneration. Furthermore, fencing alone does not lead to high status: all promising exclosures, with the exception of MLEF, were planted and had follow-up, and all unpromising exclosures were unplanted. As discussed in the "Planting" section, units with no canopy were not fenced, and do not appear to require it.

Promising *unfenced* units (27% of unfenced units) were planted (with the possible exception of EPE) and had no canopy. Most were also at the eastern end of the park where deer density is presumably lower (P. Rundell, pers. comm.).

Exclosures remove the problem of deer herbivory. Pines are susceptible to growth limitations or death from deer browsing when they are 6 inches to 7 feet tall (Ross *et al.* 1970), and repeated browsing itself can keep pines below 7 feet indefinitely. Pines are not a preferred deer food but they are eaten in winter when green deciduous and herbaceous material is unavailable (Rogers *et al.* 1981).

As discussed in the "Overstory" section below, deer spend more time browsing under canopies. This explains why exclosures appear to be necessary under a canopy but not in no-canopy units. Exclosures are especially important for white and jack pine. Red pine is less utilized by deer (Dahlberg & Guettinger 1956, Orke 1966, Rogers *et al.* 1981) and also withstands deer and hare browsing much better than white pine because it can develop adventitious buds (Marshall *et al.* 1955, from a clipping study in eastern Minnesota). Promising unfenced planted units are almost entirely red pine, even if the other species were planted.

There may be a relationship between deer browsing and overall shrub densities, but so far one has not been shown. While one might expect shrub densities to be lower with browsing, a study by Hansen and Bakuzis (1952) shows higher shrub densities *outside* 2 Itasca exclosures. In a later study of one of these exclosures (Mary Lake Deer Exclosure), Steingraber (1989) showed an increase in the difference in hazel density over time; hazel abundance increased more outside than inside the fence. There were also higher hardwood densities, particularly in smaller size classes, outside the fence.

Statewide, the deer population is much higher now than it was historically, due to increased habitat from logging at the turn of the century (Great Lakes Deer Group 1964, Krefting 1975). The elimination of wolves in Itasca by 1930 through bounty hunting is another likely cause (Hansen *et al.* 1974, Steingraber 1989). Deer populations continue to grow statewide due to wildlife (*i.e.*, deer) management, continual aspen harvesting, and creation of additional edge habitat by logging, agriculture, and other land uses (Jones 1992, Pastor 1992).

Carrying capacity, in the traditional use of the term, is a measure of how many deer an area can support, with the primary concern being the health of the deer. It is a different from, and usually higher than, the maximum density of deer allowable to maintain plant communities (Alverson *et al.* 1988). Lower yet are deer densities needed to restore pine communities from vegetation types more suitable to deer. Pre-settlement deer densities or lower are desirable but difficult to estimate. In Wisconsin, the deer population of the early 1800s is estimated to have been less than 10 per square mile (Alverson *et al.* 1988).

In the 1930s in Itasca, the deer population was estimated at 60 deer per square mile. At this time, Feeney (1935) estimated the carrying capacity of the Park to be 13-16 deer per square mile. In autumn 1945 hunting was first opened in the Park and about 2,048 deer were killed (Dobie 1959). It appears that most were killed because following the hunt, J. Zorichek estimated 30 deer total in the Park (Ross *et al.* 1970). After this the population gradually increased and by 1969 deer were frequently seen (Ross *et al.* 1970). The numbers continue to grow based on informal surveys (P. Rundell, pers. comm.) and deer harvest counts.

The high deer density in the Park is mainly a result of a high density outside the Park. The Park is a winter sink for deer populations from the surrounding area because it provides the conifer cover they seek in winter. Dobie (1959) tells of hunters with camps on the periphery of the Park to take advantage of the annual migration into the Park in autumn. Wolves have returned to the Park in low numbers, but because of the yearly immigration, it is uncertain if more wolves or more effective hunting practices in the Park can significantly alter deer pressure on pines. Wildlife management efforts outside the Park directly impede efforts to reduce deer inside the Park.

However the efforts of managers to restore pines to the Park may have contributed to increased deer pressure on pines. Resprouting vegetation, such as occurs after clearcuts, fires, or herbicide use, is especially nutritious for deer (Rogers *et al.* 1981), and such treatments are used by wildlife managers to keep deer populations high (Erickson *et al.* 1961, Great Lakes Deer Group 1964, Alverson *et al.* 1988). Furthermore, deer are attracted to resprouting areas year-round (Krefting & Hansen 1969, in winter after herbicide; Rogers *et al.* 1981, aspen suckers in summer) which may increase deer browsing pressure in managed areas over unmanaged areas. This is especially true when the cut or burned area is small enough to provide deer enough protection from weather and predators (Graham *et al.* 1963, Great Lakes Deer Group 1964, Benedict 1989).

For one Itasca management site (JP1), the manager attempted to use deer's affinity for clearcut areas to lead deer away from the planting site. Three aspen stands close to the site were felled and allowed to regenerate. The manager reports that this did not keep the deer away (P. Rundell, pers. comm.).

Brush removal release

Brush release shows up as a significant treatment in both single-treatment analyses and in some cluster analyses. Brush release in manual classification c (Figure 25c) is compounded by overstory density. 73% of brush released units were promising and 71% of units without brush release were unpromising. Brush release is not a requirement for high status: only 36% of promising units had brush removal. Promising units not released by brush removal were either fenced or had no overstory and, except for MLEF (and perhaps EPE), were planted. No cultural units were released; on most of these units the shrub competition is low or non-existent.

All brush released units were also cut (and these are the units to most likely need it), and most were planted.

The treatment was under-utilized: only 19% of units were released by brush removal. It is more labor-intensive than planting, but unlike planting it does not require the purchase of materials. Though the timing of brush removal is likely important, it is not as critical as for planting, which must be done in the spring.

Herbicide release may also be helpful, but it was not a significant factor in any analysis. (Its effectiveness is also of less interest because herbicide use is no longer allowed in the Park. The last application of herbicide in the database is fall of 1987.) Nine units were treated with herbicide release, and 3 of these were also treated with brush release. Five (56%) were promising (or 3 (50%) of herbicide release-only units). Interestingly, at the same time Hansen (1969) was testing the use of herbicides in pine regeneration, he was testing its use in increasing deer browse in several upland forest types (Krefting & Hansen 1969). Six years after spraying, the overall abundance of shrubs was higher in all forest types, particularly species of high- and medium-preference of deer.

Brush release may remove the problem of competition by shrubs, hardwood sprouts and seedlings, which is very dense on most units, especially after cutting or burning. The most abundant (and problematic) shrub in Itasca is hazel and the most problematic tree is aspen. Data are not available to compare competition from the shrub and overstory strata in the current study. Shrub-stratum competition can be more important than overstory tree competition (Shirley 1945, for red pine), but pine can eventually overtop shrubs—but not trees—if they are not too dense. A tree canopy can reduce brush, but it usually cannot reduce it enough to benefit pines, especially if brush is already established (Bakuzis 1954).

The methods of brush removal are not described in the records, but presumably the shrubs were hand cut. One would expect them to resprout, and Benzie (1977a) says hand cutting may need to be repeated several times at 2-3 year intervals. Of 11 brush released units, 4 were treated more than once[11] and an additional 3 were also treated with herbicide release. The 4 units with only one release were all promising (plus 2 with brush plus herbicide release and 1 with 4 brush releases). Therefore, it appears that, at least under some conditions, a single treatment reduced shrubs long enough for pines to overtop them.

The *Ribes* eradication of 1919 through 1960 was not included in this study. The purpose was not brush release, but rather elimination of a host of white pine blister rust. The effectiveness of this method is now doubted (Anderson 1973). It is extremely unlikely that the density of this shrub was high enough for the eradication program to have an impact on the competition for pines.

The possible increase in shrub and hardwood competition this century is discussed in the "Fire" section below.

II.H.2.b. Detrimental treatments

Prepropagation overstory (Tree canopy)

In all analyses, one or more overstory variables (overstory code, overstory density, canopy, dense canopy) show up as statistically significant factors. Only 1 of 13 units with a *dense canopy* was promising (MLEF); this is an overstory of red pine (overstory code of 7, dense pine), and the pine regeneration is white pine, the only Itasca pine species that can tolerate such shaded conditions. Dense canopy units were not planted and only 2 were released.

Six of 31 units (20%) with a *scattered canopy* were promising. These 6 promising units make up 35% of all promising units. The range of overstory densities comprising my "scattered" canopy category is quite large, but this variability does not explain the differences in status among scattered canopy units. The promising units did not contain appreciable amounts of deciduous trees in their canopies. More specifically, all were felled of jack pine and hardwoods (primarily aspen) and left with a scattered red pine overstory (overstory code = 4). Such felling may be beneficial, but it is not enough: there were also 12 unpromising units with a scattered pine overstory. The treatments applied appear to be more important: all 6 scattered canopy units were both fenced and planted, while the unpromising scattered canopy units were either not

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[11] The second brush removal of LBAF & LBAC was considered site preparation in the analysis (based on primary purpose), but because there were some existing seedlings at the time, it is counted as release here.

fenced (21 units) or fenced but not planted (1 unit, WPKF). The 3 scattered overstory cultural units were unpromising.

The 15 units with *no canopy* were either clearcut or cultural (or burned in the case of EPE). Ten (67%) of the no canopy units were promising: 6 of 8 clearcut units, 3 of 6 cultural units (with HPL counted as cultural), and EPE. Therefore there is no evidence that either method of canopy removal is better than the other.

Jack pine and red pine are shade-intolerant species. These pines typically only regenerate after a catastrophic disturbance that removes almost all of the canopy for jack pine, and much of the canopy for red pine (Ahlgren & Ahlgren 1960, Bergeron & Brisson 1990). They may be able to take advantage of large gaps created by blowdowns, but not the small gaps more typical of Itasca. In a survey of 2 Itasca blowdowns that created gaps of up to 265 m^2 in size, Webb (1986) found no red or jack pine seedlings or saplings. Instead, the gaps were filled in with pre-existent shade-tolerant trees and shrubs, or in the pine-fir stand, aspen and birch. When Kurmis (1985) resurveyed the upland forest types he had surveyed in 1965, he found that new gaps had not been filled in by the 1965 advanced pine regeneration; aspen and birch filled in gaps in the jack pine - red pine type and balsam fir filled in under the pine-spruce-fir type. Much of the 1965 pine regeneration had disappeared, including all of the saplings (>30 cm tall).

White pine has an intermediate level of shade tolerance. Seedlings and saplings can survive under a dense canopy or significant shrub densities, but are slow-growing under those conditions. In north-central Minnesota plantations, white pine does best at 40-60% crown closure; at lower overstory covers it can have problems with tip weevil (Rajala 1992). Under these conditions, deer are the only problem they have experienced in growing white pine at Rajala Lumber. In Itasca white pine appear to be unable to grow beyond the suppressed condition, even when the canopy is open, because of browsing by deer. The only unit in which it was promising was the fenced, dense canopy Mary Lake Exclosure. Webb (1986) found white pine seedlings in her study of Itasca blowdowns, but no white pine saplings, an absence that she attributed to deer browsing.

The problem of deer browsing is discussed in the "Exclosure" section above. An overstory can worsen deer problems for pines, which is likely the reason that, under a canopy, only fenced units were promising. In winter, deer prefer the shelter of evergreen forests (Mooty *et al.* 1987), and this is the time they feed on pine seedlings (Rogers *et al.* 1981). Large open areas have colder conditions, higher snow depths, and increased risk of predation.

A further interaction of canopy and deer is that under a canopy it takes longer for pines to grow out of the range of deer.

A tree canopy might be used to reduce shrub cover, which can be more deleterious to pines than tree cover (Shirley 1945, for red pine). However, Bakuzis (1954) found that a tree canopy in Itasca was usually not enough to reduce shrubs to a level tolerated by pines, especially if the shrubs are already established.

Fire

Fire was a significant negative factor in both individual-treatment analyses. It did not show up in the cluster analysis or manual classifications, except manual classification b (Figure 25b). In this classification, fire separates promising from unpromising planted, no canopy units; but only 2 are in the fire category, and fire appears to be unrelated to the low status of these 2 units: for JP1U the problem is deer (other burned portions of JP1 were promising) and for SLEW the problems appear to be deer and high shrub and aspen densities (it also unpromising before the fire).

Fourteen prescribed fires were applied to 8 areas made up of 20 units. Of the 20 units only 2 (10%) were promising. It is not clear if the high status of JP1Y and JP1M is related to the prescribed fire (see intraproject comparisons). But considering the low status of JP1U, the unfenced burned portion, fencing and follow-up plantings were critical to the high status. The other promising burned unit is EPE, which was burned by a wildfire and probably planted. Unfortunately I have no information about the severity of this fire.

The association of prescribed fire with low status is surprising because pine communities are fire-maintained, and therefore we would expect fires to help, rather than hinder establishment. The possible reasons are 1) detrimental treatments or site conditions (or both) are associated with fire, 2) the fires are not replicating the natural fire regime, and 3) current conditions are different than prior to logging and fire suppression.

Associations with other treatments

All but 2 of the 20 prescribed fire units (TSTD and TSTM), were cut before the fire. On most of these units, canopy hardwoods were removed and canopy pines were left. Also, all but 2 units (JP1U and SLEW) had a scattered or dense canopy. No prescribed fire was intense enough to remove the canopy. This means that any seedlings that germinated or were planted after fire had the disadvantage of a canopy, plus—depending on the interaction of fire and felling—possible increased competition related to resprouting of shrubs and hardwoods after felling.

Only 3 burned sites (8 units) were fully planted (JP1, SLE, probably EPE) and 3 (4 units) were fenced (JP1, LBA, WPK). The only promising burned units are JP1Y, JP1M, and EPE. Jack Pine 1 is the only burned site which was both planted and fenced, and East Park Entrance (presumably planted) developed at a time of very low deer density following the opening of hunting in the Park. Jack Pine 1 also had the most follow-up of any of the burned sites.

Prescribed fires have not replicated the natural fire regime

It is understood that most if not all of the current pine forests in Itasca (Spurr 1954, Frissell 1971) originated after a catastrophic fire. Fire suppression efforts began in Itasca in about 1894 (Spurr 1954) and increased over time. In 1908 students of the University of Minnesota Forestry School constructed a 16-foot wide firebreak surrounding the entire Park (Thoma, n.d., Dobie 1959). Since 1922 fire suppression has been so effective that fire has been virtually absent from the Park (Frissell 1971). The first prescribed fire in Itasca was in the early 1960s (Thoma, n.d.), and the first with enough information to be included in this study was in 1971.

Important aspects of fires which may be different in prescribed fires as compared to natural fires are fire behavior, season, and frequency.

1. Fire behavior

Two fire effects that are important to vegetation response are humus consumption and scorch height (Johnson & Miyanishi 1995). The term *severity*, as defined by Rowe (1983), describes the degree of soil heating and consumption of humus. *Intensity* describes the heat output of the flaming front of the fire and is directly related to scorch height (Johnson & Miyanishi 1995). Intensity apparently has little direct effect on underground heating (Bryan 1959, Schimmel & Granström 1996). Rather, severity depends more on the moisture content of litter and humus and on the speed of the fire (Johnson & Miyanishi 1995).

Fire severity is of primary consideration for pine regeneration. A fire of most benefit to pine germination and survival consumes all humus to expose mineral soil and kills underground rhizomes of shrubs and hardwoods to prevent resprouting. Mineral soil is beneficial for germination and early survival of all 3 pine species (Ahlgren and Ahlgren 1960, Ahlgren 1976), especially for red and jack pine, and killing hardwood and shrub rhizomes lessens competition from sprouts, which can be imposing. If a fire kills only the above-ground stems of shrubs and hardwoods, most can resprout at higher stem densities than before fire. This is especially true of hazel (*Corylus cornuta* and *C. americana*, Buckman 1964) and aspen (*Populus tremuloides*, Perala 1995), the most important pine competitors in Itasca. Hazel rhizomes are predominantly in the upper 6 inches of soil (Hsuing 1951) at or near the humus-mineral soil contact and should be killed or severely damaged if the humus is entirely consumed (Buckman 1964).

It is likely that none of the prescribed fires in this study (and to my knowledge, in Itasca at all) has been as severe as most natural fires. Of the 9 prescribed fires for which I have managers' comments, 3 were described as "good" and the rest had mixed or poor results. Of course it is unclear what is meant by "good." One of the "good" fires burned both promising units; the managers' comments were, "good, fairly hot in some places" (P. Rundell, pers. comm.), and "fairly complete burn and hot enough to burn off vegetation at ground level. Too much frost to kill," (DNR 1981).

It appears that even the "good" prescribed fires did not expose mineral soil through most of the burn area, and it appears that all fires stimulated copious shrub and hardwood tree resprouting. Vigorous shrub and hardwood resprouting was noted for all units for which I have information, including the uncut TST, and shrub and aspen densities were very high on all units when I visited in 1995-1996. Aspen and hazel account for most of the sprouting biomass. I do not have values for most units, but the highest densities were recorded from LGW: there were 32,500 aspen suckers/acre and 167,577 hazel stems/acre following fire (Hansen *et al.* 1974). The overall low status of burned units could be due to the competition resulting from this resprouting.

This is not to say that natural fires never stimulated shrub or hardwood resprouting—indeed, it appears they often did so—but natural fires have a greater chance than prescribed fires of being severe enough to kill underground rhizomes. The frequency and season of fires are also very important in this regard, as discussed below.

Fire intensity is a consideration for pine regeneration when partial or complete removal of the canopy is desired. None of the prescribed fires removed any of the canopy. Canopy removal is beneficial for all pines, but particularly jack pine. Itasca is in the range of the open-cone (non-serotinous) ecotype of jack pine (Minn. DNR Natural Heritage Program 1993), so fire is not required to open jack pines cones in the Park. However a canopy fire will increase the number of cones which open at the appropriate time after fire, and, more importantly, will reduce canopy cover. Shade intolerance is probably the most important issue for jack pine in Itasca. Red pine and white pine benefit the most from partial canopy removal. It is important for some fire tolerant adults to remain in the burned area as a seed source (Frelich & Reich 1995). Ideally, an intense canopy fire will also be severe or be preceded or followed by a severe ground fire.

Reasons for the probable lower intensity and severity of prescribed fire as compared to wildfire include: 1) the prescribed fires are by definition in control and safe; 2) wildfires tend to occur in the driest years and driest days, conditions that are avoided by fire managers for safety reasons; 3) prescribed fires tend to be smaller than wildfires and therefore cannot gain as much momentum (and furthermore are more attractive to deer (Benedict 1989)); and 4) most prescribed fires are logged first, and logging stimulates shrub resprouting itself.

2. Season

In Minnesota, severe fires are much more likely in the summer than in the spring or fall (Buckman 1964, Ohman & Grigal 1981). As long as the humus layer remains moist after snowmelt, it will not be significantly consumed (Johnson & Miyanishi 1995). Shrub and hardwood rhizomes are unlikely to be killed without significant humus consumption, because the humus insulates the mineral soil. Summer fires may also be more damaging to shrubs and hardwoods because rhizome reserves are likely relatively depleted during the summer (Buckman 1964).

Summer is nearly always hotter and drier than spring or fall in Minnesota, and historical stand-initiating fires likely occurred almost entirely during these months, during very dry periods (Heinselman 1973). Unfortunately, good prescribed burn conditions—in the sense of actually starting a fire that carries—are less frequent in the summer (Buckman 1964).

In a study of prescribed fires in north-central Minnesota, spring (mid-April to mid-May) burns stimulated resprouting of hazel, and hazel continued to increase in abundance with each subsequent spring burn (Buckman 1964). Summer burns, on the other hand, resulted in less hazel resprouting than spring burns, and after the fourth burn, a much lower hazel abundance than prior to burning. A comparison of 2 wildfires in northeastern Minnesota showed similar results: the spring fire was followed by vegetative growth while the summer fire removed most vegetative structures and was revegetated primarily by seed (Ohmann & Grigal 1981).

Conditions for fall burns are more variable, but the humus usually is moist again (Buckman 1964) due to prevailing weather patterns.

As far as I know, only one summer burn has been attempted at Itasca, but "in spite of no precipitation for several weeks before the trials, the fire did not carry through the rather lush growth of herbs and shrubs," (Hansen *et al.* 1974). Spring and fall burns have been applied equally, in different combinations on the same site. There have been too few prescribed fires, and information is too limited, to judge the relative effectiveness of these timings. The effect of the fires is overshadowed by the other treatments, the site conditions, and the fire conditions.

3. Frequency

From 1712-1900 there were scar-forming ground fires on average every 16 years in Itasca (range of 2 –53 years, Frissell 1971), burning a given point about every 20-40 years (Frissell 1973). Frissell (1973) estimates the rotation of catastrophic crown fires to be every 150 years. However, shifts in fire regime have occurred every 10-40 years in the Itasca area in the past 750 years (Clark 1988), with frequency intervals ranging from 8.6-10 years in warm dry periods to 13-43 years in cool/moist periods (Clark 1990). It is likely that the variation in fire frequency is as important as the average frequency itself. For example, 20-40 year periods without intense fire are important for the survival of red and white pine, which do not become fire tolerant until about age 20 (Clark 1990).

Periodic ground fires can keep shrub abundance low and the overall understory sparse in red and white pine stands, at least in northeastern Minnesota (Frelich & Reich 1995). Without these periodic ground fires, a catastrophic fire may not regenerate a new pine stand. Periodic ground fires may also allow pines to take advantage of gaps by maintaining low humus depths.

Unfortunately, repeated burning has not been adequately tested in Itasca. Of the 8 prescribed burned areas (composed of 20 units), 3 were burned once (7 units), 4 twice (11 units), and 1 three times (2 units). Multiple burns were from 1 to 4 years apart, which is too frequent to allow for survival of pine regeneration from the earlier fires. However, little regeneration survived the first fires, and the repeated burns were an attempt to reduce shrub and hardwood competition. But based on the work of Buckman (1964, hazel reduction) and Buckman & Blankenship (1965, aspen reduction), more than 2-3 fires are needed to reach that goal.

<u>Current conditions are different than prior to logging and fire suppression</u>

Homesteading and logging at the turn of the century (from about 1880-1917), followed by frequent post-logging fires (Spurr 1954, Frissell 1971) and then fire suppression, may have resulted in higher densities of hardwoods and shrubs in Itasca forests (Hansen 1956). Higher densities could reduce the opportunity for severe prescribed fires because of increased green vegetation, and would result in more resprouting following fire. However, no historical change in shrub density has been documented (Steingraber 1989). In fact, there are several historical accounts of high shrub or hardwood densities following fire in Itasca (Spurr 1954): Schoolcraft Island in 1871 (Chambers ("underbrush")) and 1891 (Browner (birch, basswood, aspen)), northeast of Douglas Lodge in 1879 (Hall (hazel, aspen)), and south of Elk Lake and west of L. Itasca in 1880 (Garrison (aspen, birch)). The area northeast of Douglas Lodge burned again in 1886 and is now a dense stand of jack, red and white pine (Buckman 1964).

While there were areas and times of high aspen density in the late 1800s, the species was not nearly as abundant on the landscape as it is today. Logging favors aspen because aspen rhizomes usually survive after logging (unlike pine), and aspen does not require a mineral seedbed to the extent that pine does. The larger area of aspen forest both within and around the Park provides a greater aspen seed source. Aspen seeds can disperse long distances and germinate in a wide variety of disturbed areas (Zasada *et al.* 1992).

In contrast, the population of pines in and around Itasca is lower than the 1800s due to logging and aging of the trees. Therefore the pine seed and pollen source is lower than before. Furthermore, seed dispersal distance is much lower for pine than for aspen (Zasada *et al.* 1992). The immediate problem for pine is low dispersal potential relative to aspen; there may also be a longer-term problem of reduced genetic diversity and therefore evolutionary potential.

Fire suppression may have allowed for the build up of litter and humus on forest floors (Clark 1988). Thicker litter and humus layers are more difficult to burn through to mineral soil because they take longer to dry. A thick litter or humus layer also decreases the chances of pine regeneration without fire. On the other hand, removal or fragmentation of slash, litter, or humus during logging and site preparation could reduce the heat, spread, and duration of fire close to the ground, such that even if mineral soil is exposed the rhizomes of shrub and hardwood competitors will not be killed.

Climate is also different today than it was in the 1800s (and previous) and may be an important factor in the condition of the forests and fires today (see discussion of climate above).

Salvage logging became allowable in the Park in 1901 and was used very extensively to generate money for the Park and Minnesota state government (Dobie 1959). It is still used in the Park, although not as extensively. Salvage logging has reduced fuel loads and reduced microsites favorable for pine germination (Webb 1986).

Mechanical site preparation

While mechanical site preparation is not a statistically significant factor in any analysis, it has an indication towards unpromising units. The purposes of these treatments are to scarify soil and reduce competition. The success of fulfilling these purposes is variable. The treatments are quite harsh to the site, particularly the soil, and are not used in the Park any more.

II.H.2.c. Notable exceptions among units

Some units are almost always exceptions to the correspondence of unit classification by treatment to status.

Mary Lake Deer Exclosure Fenced (MLEF) is an exception in every classification. In cluster analyses it falls into Status C groups even at lower levels of the hierarchy. This is because it is the only Status A unit with a dense canopy and is 1 of 1 or 2 Status A units which were not planted. It is unusual among Status A units in having no follow-up. It is also the only Status A unit of primarily white pine.

It is also unusual that brush, especially hazel, was not a problem. Circa 1937 Amidon (Ross *et al.* 1970) reported that, "*Corylus* brush is sparce [sic] except in the southeast part where it is dense."

The reason for the high status of this unit is unknown.

East Park Entrance (EPE) is the other Status A unit that may not have been planted. It is also 1 of 3 Status A burned units (2 of which are the same burn site). It is the only unit prepared by a wildfire, which perhaps created good conditions for pine regeneration. It was not fenced, but the timing was coincident with a dip in the deer population following opening of the Park to deer hunting. It is one of a few Status A unfenced units with no jack pine. Unfortunately very little is known about the fire, the treatments (including whether or not it was planted), or the overstory following fire.

Jack Pine 1 contains 2 units (**JP1Y, JP1M**) which are 2 of 3 Status A burned units. They are not exceptions in classifications by treatment, however, because they had enough other treatments similar to other Status A units. It may be that these units are Status A *despite* prescribed burning. Jack Pine 1 is the only burned site that was both planted and fenced, and it also had the most follow-up of any of the burned sites.

JP1U, **RP4**, and **SLEW** are Status C units commonly in the "Status A group." They are the only Status C units with no canopy:

Jack Pine 1–Unfenced was subjected to heavy deer browsing, which appears to be the primary problem based on intrasite comparisons.

Squaw Lake East–West is the only unit that had aspen sprouts knocked down by a bulldozer before being burned. (The treatment bent over the 4.5 – 6 m tall (8 year) saplings and peeled bark from their stems.) According to P. Rundell (pers. comm.), the combination of blading and fire kept aspen back for 3 years. The site was burned again at that time (1978), and it appears that the aspen sprouting was exceptional. I believe it had the highest aspen density of any other unit I visited in 1995-1996. By the time the unit was planted, 4 years after the second fire, there was probably a very dense layer of aspen suckers acting as a low, effective overstory.

Red Pine 4 is a small unit with considerable encroachment by hardwood trees and shrubs. Although it is an old field, the seedlings are subjected to shading by the surrounding hardwood forest and its progeny. Pocket gophers are also a problem at this site, and there may be more deer damage due to the small, protected size.

Another Status C unit, **Roy Hemrick Homesite**, is an exception in 1 manual classification along with **Red Pine 4**. These are the only Status C planted cultural units. Trees and shrubs have established in this field to a degree that I classified it as having a scattered overstory (which is why it did not show up as an exception in most classifications). The other planted cultural unit with significant light competition (scattered overstory) is Miller's Old Road, which was Status B. Trading Post Field–East is the other cultural unit with a scattered overstory, but it was not an exception in classifications because it was probably not planted with pine.

II.H.2.d. Important treatments (and combinations) that have been under-utilized

Resources are very limited for Park management, and the resources in turn limit the ability for successful pine regeneration. Treatments that have been used in the past, but in my opinion have not been used enough (prior to 1995), are discussed here.

Follow-up

An important aspect of high status appears to be follow-up—protection, release, and repropagation—regardless of the specific treatments applied. Many Status A units would have been Status C without follow-up, because they had little to no pine regeneration after the initial treatments.

Persistence in treatments has generally been lacking, and I believe it is a major problem to the pine restoration efforts. For example, a lot of money is put into deer fences, so one would suppose that deer-fence sites would be especially well monitored and cared for. However, there is complete lack of regeneration in several recent exclosures. These were sites tested for burning, but after a few attempts to burn it appears that the projects were at least temporarily abandoned.

Flexibility and coordinated effort

I believe another problem has been an insufficiency of flexibility and coordinated effort. So many agencies have worked simultaneously on the Park, with no one person to coordinate efforts. Each individual with responsibility in the Park has had many additional responsibilities outside the Park, which makes coordination even more difficult. Furthermore, there are constraints of the bureaucratic system that make coordination and flexibility difficult.

Here is an example of a planting effort in the spring of 1994: one person decided to plant a site the next spring, another ordered the trees from a nursery in the fall, the nursery reserved seedlings for the Park and pulled the trees on a predetermined date in the spring, another person went to pick up the trees (a little late), a travelling planting crew was hired for specific dates and planted the trees on these dates even though they noticed that many of the roots were damaged and it was a dry period. There was miscommunication when they were told where to plant which species, and red pine was planted in an area meant for jack pine. A large number of seedlings, especially jack pine, died immediately after the planting.

Pine species

Red pine is better represented in Status A units than either white or jack pine. The difference is due partly to better survival of red pine, and partly to preferential propagation. As best as I can determine, red pine was a target species for 40 units, whereas jack pine was a target for 29-31 units and white pine for 11-17. Fourteen Status A units have substantial amounts of red pine, and 9 of these are almost entirely red pine. In contrast, about 5 Status A units have substantial jack pine and only 2 have substantial white pine. One of the white pine units has red pine in equal amounts, plus some jack pine, and most of the jack pine units have more red pine than jack pine.

Deer damage appears to account for much of the lower survival of white and jack pine, and canopy cover is an additional problem for jack pine. It is surprising that there have been no restoration attempts of jack pine alone, considering that the species often occurs naturally in nearly mono-specific stands.

Treatments

Overall, there has not been enough protection or release, considering the apparent effectiveness of these treatments. They comprise only 7% and 9%, respectively, of all treatment applications, to 24% and 29% of the units. While these treatments are expensive, in my opinion they have been under-utilized while site preparation has been over-utilized (comprising 50% of all treatment applications). While no stage is significantly related to status, Status A units tended to have more protection and release and less site preparation.

All units were site-prepared in one way or another. Cultural treatments (agriculture, homesteading, etc.) are counted in this group, but only account for 4% of all treatment applications (8 units). Old fields have been planted in the past, but I only had records for recent revegetation attempts. Most are Status B because they are young. None has been fenced, burned, or released, and few have been site prepared other than the initial cultural treatment. It is clear that for at least some old fields (particularly large and open with no shrub encroachment), these treatments are not needed.

Brush release was used only once as a site preparation—one instance applied to 2 units (Lagoon Burn Area). It was not effective in this case, but perhaps should be tried as an alternative to the more disruptive site preparation options.

Most units (53%) had a scattered canopy. Because canopy was an important negative factor, it appears that complete canopy removal has been under-utilized. However, the range of overstory densities comprising my "scattered" canopy category is quite large. Research may be needed to determine the maximum canopy densities allowable for pine survival and growth in Itasca. In particular, managers will continue to want to leave at least some older pines as a seed source for red and white pine. Indeed, such a situation is typical of red and white pines after natural fire, and many existing older pine stands in Itasca are multiple-aged (Frissell 1971). Managers will instead want to focus their efforts on hardwood overstory and shrub cover.

Planting under an intact overstory has not been attempted, probably because managers have not wanted to waste costly seedlings in these conditions. Low-cost experiments of planting white pine in existing exclosures with overstories could be performed, especially as the existing pine canopies begin to break up.

II.H.3. Recommendations

Many pine regeneration problems have probably already been solved by the hiring of a Resource Manager for Itasca State Park. In fact, many of the following recommendations are already being implemented. Most importantly, this person can provide cohesiveness and coordination that was formerly lacking from Park management. Furthermore, because she has only one park to work with, there can be more focus and follow-up applied to management activities. Of course the utility of this new position to pine restoration will depend on how much funding and how much of the manager's time is available for restoration work.

Clarify goals

I had a difficult time determining how to rate the status of the treatment units in this study, because the goals of these sites had not been clearly laid out, at least not in a format that was available to me. I recommend that the goals for each site be documented in detail (*i.e.*, more than just "pine regeneration") each time they are created or changed. Furthermore, the overall goals for pine restoration in the Park should be more specific.

<u>Document</u>

Past treatments have been poorly documented and this has been very unfortunate for today's managers (not to mention this thesis!) who are trying to understand what has been done and make decisions about what to do now. Documentation should indicate the goal of the treatment, list the methods considered to reach the goal, and give justification for the method chosen. When future managers look at the treatment, they may wonder why something else was not tried, and the documentation will hopefully answer their question and give them more information about whether or not to try a new idea.

It does take more time to do this, and time is limited. Early managers probably felt the "emergency" nature of the situation and had constraints on their time, but in retrospect we see that time for documentation would have been well-spent. They did not solve the "emergency" then, and today there is still hope.

<u>Stop salvage logging</u>

Salvage logging is still common practice in the Park, ostensibly for "hazard removal and sanitation cuttings" (Hansen *et al.* 1974). But I have observed that there is still considerable salvage for other reasons— to "clean up the forest" for visitors and probably because it is a long tradition that is hard to break. It is not acceptable. Not only are standing-dead and fallen-dead trees important to a variety of animals, plants, fungi, and bacteria; fallen logs are also important germination sites for pines (see Webb 1986) and contributors to fuel loads.

<u>Do larger restorations</u>

Larger disturbances and restoration projects tend to have less edge effect and fewer deer problems, and in general they are more similar to natural disturbances and are more cost-effective. The sites in the database range from 0.5 to 230 acres, with an average of 21 acres; these small sizes have likely compounded the deer problem.

<u>Take advantage of existing deer fences</u>

Deer fences are expensive but effective, and existing exclosed sites should be high-priority for follow-up. There are 2 unpromising exclosures with virtually no pine reproduction and another medium-status exclosure. The 3 promising 1988 exclosures would all benefit from brush release. The older SLEF exclosure is no longer needed, as the pines are out of the range of deer browsing, and the fence could be moved to another location.

Control deer

Controlling deer populations is generally less expensive than fencing and should be attempted with greater effort. The population must be kept artificially low until the time when successful restoration will itself help maintain a lower deer population. Unfortunately, controlling deer is a very difficult problem, and it has been a struggle for a long time. The managers of the hunting program have tried various incentive programs to entice hunters to kill more deer and to kill does. But they report that most hunters are too interested in trophies to be especially interested in does, and most hunters search out high-density areas and stick to roads and easily traversed areas.

Methods that could really decrease the deer population (such as sharp shooting, extended hunting seasons at more effective times of year, and requirements for doe harvest) can meet strong opposition from deer hunters, Park visitors (who like to see deer), and animal activists, especially when deer reductions outside of the Park would be required. The Park is a good wintering area and it is possible that immigration is so high from surrounding areas that it does not matter how many deer are killed in Itasca. Coordination with agencies that manage land and deer outside the Park is critical.

Use more fire

Fire is the dominant factor driving the existence of pines in Itasca, and has been too infrequently used for restoration and management. The silvicultural treatments that have been used in its place are generally meant to grow pines at the expense of anything else that might grow on a site. But the goals in Itasca State Park are different than silvicultural goals. The entire pine ecosystem should be considered, including understory and overstory plant associates, animals, and soil structure. The long-term effects of many silvicultural treatments are either not known, or are known to be deleterious to the soil or other species (often intentionally). Such treatments are undesirable in Itasca.

Fires need to be larger and more severe, and they need to be used more (*i.e.*, more frequently in some areas, and in more areas of the Park). The boundaries of "safe fire" must be pushed and canopy fires should be attempted if possible. In addition to the conditions that will allow the fire to burn, the desired effects of the fire on the vegetation must be considered when prescribing a fire.

The fires that occurred prior to 1994 were insufficiently documented and experimental to teach us much about beneficial burning techniques in Itasca. The details of fire behavior are important (Johnson & Miyanishi 1995), and the effects of fire behavior on Park vegetation needs to be better understood. An experimental approach to fire severity, intensity, season, and frequency should be used, and fire behavior should be carefully documented. Average historical fire frequencies should be used with caution (Clark 1988, Johnson & Miyanishi 1995); they may no longer be appropriate under current conditions, considering the variability of the past (Clark 1988) and the possible need to recover from logging and fire suppression.

Although little is known about the behavior of past prescribed fires in Itasca, they are a good opportunity for immediate "long-term" experiments of repeat burning.

Use more release

Brush removal appears to have been effective, but it has been little used. It is labor intensive, but, unlike planting, there is no cost of raw materials, skilled labor is not required, and the timing of the treatment is not as critical. Volunteer labor would be an inexpensive way to greatly increase this treatment in the Park. Especially as more fire is used and deer damage is controlled, replanting could be partly sacrificed to increase brush removal.

Propagate more white pine and jack pine

All 3 pine species have been important components of Itasca vegetation, but red pine has been over-represented in restoration efforts. More effort is needed to restore white and jack pine if the goal is to maintain the relative pine abundances of the past. A better balance of the species is also better preparation for climate change, which may favor one species over the others. Also, more attention should be given to desired combinations of tree species in the future communities. In particular, more pure stands of jack pine are needed. More deer control is particularly needed for white and jack pine.

Allow for flexibility in the timing of treatments

To increase the chances of pine regeneration following treatments, managers need to be able to react to different weather conditions and other conditions to the survival of pine. The timing and location of burning and propagation must be especially flexible. Certainly flexibility is difficult with limited resources in a system of specialized labor, but applying more resources to a flexible system should be easily paid off in the reduction of losses incurred by doing work at inappropriate times.

To increase flexibility one could, for example, pay more for on-call burn crews, manage employees' workloads so they are able to drop other work to participate in a last-minute burn, consider ideal conditions to be "emergency" situations (such as the bark beetle population surge of 1995, which saw immediate action), appeal to volunteers for extra last-minute help, make better arrangements with nurseries or maintain Park-run nurseries (with employees hired specifically to do so).

Do more

Sites: It appears that a significant factor affecting pine regeneration status is chance. The more restoration projects, the better the chance of successful regeneration.

At each site: Persistence in treatments at a given site has been lacking, and I believe it is a major problem to the pine restoration efforts. A pre-requisite to follow-up is monitoring the site.

Of course, there is a trade-off between more sites and more effort at each site, and a strategy is difficult to come by. Part of the difficulty is in knowing when to give up on a site. Pine restoration is simply a difficult task, and one cannot expect to always succeed. When a site is abandoned, the reasons should be documented for the benefit of future managers. Ideally site-selection and the application of treatments appropriate to a site will improve over time.

Changing the nature of efforts at each site can be helpful in this trade-off. For example, resources can be used more efficiently by increasing the use of volunteers and treating large areas with fire rather than small areas with mechanical site preparation.

Take climate change and other changes in current condition into account

Climate change makes the work of the forest manager even more difficult. While there is a legal mandate to "preserve intact the primeval pine forest," (General Laws of 1907, Chapter 90), it is difficult to know if that vegetation is still most appropriate for the area. Two-thousand years ago the Park was deciduous forest. What should natural communities be 2,000 years from now? Were pines in Itasca a chance, one-time event? We need to decide how far to push in our restoration efforts.

Further study

- Studies to describe the biotic and physical characteristics of existing (and historical) pine communities in Itasca. The descriptions will help the formulation of more detailed goals for restoration and provide information for future generations. Such studies could include preserving local seed (if possible) of component species of the pine forests, including understory species.
- The overstory density of the units in this study was not measured. A more detailed comparison of overstory density and composition to pine regeneration status would be helpful, as would a study of the effect of seed tree density (seed source and nurse tree effects) on pine germination and survival.

- Kurmis (1969) surveyed natural regeneration in the Park, but he only looked at forested sites. A survey of old fields, lake shores, and other relatively open areas would be useful, with special consideration of depth of humus, slope, aspect, and shrub and overstory densities.
- There is considerable need for detailed studies of prescribed fire regime and its effect on pine regeneration.

Conclusions

Twenty-nine percent of the studied units had a promising level of pine regeneration. The proportion for all treated units in Itasca State Park is most likely lower, because there was a bias in my unit selection towards promising units.

There was an average change in pine density of –140 pines/acre/year for a selection of monitored units and –9.2 pines/acre/year for the subset of promising monitored units.

Management of the studied units did not increase pine regeneration densities over natural densities found under canopies by Kurmis (1969) in 1965, but it did increase growth on some units.

No one treatment guaranteed a high or low status of the studied units. Follow-up in the form of protection, release, and additional propagation was important. Individual treatments that appear to have been beneficial to high status are planting, exclosure, and release by brush removal. Treatments and conditions that appear to have been detrimental to high status are overstory and prescribed fire.

Promising units were either planted and had no canopy, or were fenced and planted with a scattered pine canopy. (The combinations of no canopy/not planted and no canopy/fenced were not attempted.) There were a few unpromising planted/no canopy units, but no fenced/planted/scattered canopy units were unpromising. The exceptions are Mary Lake Deer Exclosure (the only promising unit with a dense canopy, not planted, and of primarily white pine) and East Park Entrance (the only unfenced burned unit, and possibly not planted).

There are several possible reasons for the "failure" of prescribed fire. 1) All prescribed fires occurred under a scattered canopy, and only the few promising fire units were both planted and fenced. 2) The prescribed fires have not been severe enough to reduce competition or create a seedbed favorable to pines, perhaps because none was a summer fire, fires have not been frequent enough this century, and the prescribed fires have been too small and "safe." 3) Changes in conditions since logging and fire suppression may have decreased the effectiveness of fire. Possible changes include an increased humus depth, change in fuels, decrease in pine seed source and increase in aspen seed source, increase in deer density, and climate change.

Not all treatments or treatment combinations have been thoroughly tested. Especially needed is more experimentation with fire, more protection from deer, more release, and more follow-up in general. White pine and jack pine are poorly represented on promising units; they have been under-used and have had lower survival than red pine.

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Appendix 1: Sources of information in the database

Published papers

- Effects of long-term deer exclusion on a Pinus resinosa forest in north-central Minnesota (Ross *et al.* 1970)
- The Itasca Story (Dobie 1959)
- Ecology of upland forest communities and implications for management in Itasca State Park, Minnesota (Hansen *et al.* 1974)

Theses

- The effects of past and current land disturbances on Squaw Lake, Minnesota and its watershed (Patterson 1978)
- The interrelationship of fire, conifer seedling regeneration, and forest rodents (Tucker 1981)
- Deer browsing, plant competition, and succession in a red pine forest, Itasca State Park, Minnesota (Steingraber 1989)

Files of University of Minnesota Professors

- Dr. Henry Hansen (files stored by John Tester and Becky Marty; see below for specific documents)
- Dr. Vilis Kurmis
- Dr. John Tester (in particular, monitor data for Priority Sites collected by the Techniques Subcommitte (John Tester, John Ross, Paul Rundell, others; 1986?) and associated relevé maps (Paul Benson Lender's, 1987)
- Dr. Don Lawrence (files stored by John Tester)

Itasca State Park Naturalist Brochures (Interpretive Services)

- Landmark Interpretive Trail Guide
- The LaSalle Lagoon Experimental Pine Regeneration Area
- Forestry Demonstration Area Trail Guide
- Itasca Imponderables, Number 2 ("The Mississippi Headwaters," 1989)
- Itasca Imponderables, Number 6 ("Picnic Shelters," 1994)

Ben Thoma documents

- Early Tree Planting in Itasca State Park....a.k.a...A Very Expensive Way to Feed Deer (1994, information based on Dobie (1959) and 3 letters of P.O. Anderson)
- Deer Exclosures of Itasca State Park (Ben Thoma 1988, containing original CCC records)

DNR Parks and Forestry forms

- Forest Development Records (Minnesota Forestry personnel, stored in a variety of locations)
- Forestry Planting Record (Minnesota Forestry personnel, stored in a variety of locations)
- DNR Cover type map (DNR personnel, stored in a variety of locations)
- DNR Planting Record (DNR personnel, stored in a variety of locations)
- Timber Appraisal Report (DNR personnel, stored in a variety of locations; some appear to be just plans)
- Prescribe [sic] Burn Proposal and Report (DNR personnel, stored in a variety of locations; show desired and actual accomplishments)
- Forest Development Proposal (DNR personnel, stored in a variety of locations)
- Special Fuelwood Permit (Forestry Personnel, stored in a variety of locations; usually for salvage of dead and down timber for fuelwood)
- Herbicide spraying log (agency unknown, stored in a variety of locations)

Paul Rundell's records:

- History of Priority Sites (most reliable)
- Printout from Paul Rundell's computer files (less reliable)
- Itasca Resource Management Sheets (put together for a discussion at the University of Minnesota; done from memory and some notes by Paul Rundell and helpers)
- Personal communication (1994-1996)
- Itasca State Park 1994 Planting Plan

Documents from the files of Henry Hansen and Vilis Kurmis

Many of these reports can be found in "Research proposals and reports on ecology and management of Itasca State Park Forest from 1956-1978," Henry Hansen 1987, Hansen's own collection of some of his work.

- Summary of Treatments Given to Field Plots in Itasca State Park for the Purpose of Encouraging the Establishment of Coniferous Regeneration (Henry Hansen, 1952)
- Proposed Management Program for the Itasca State Park Forest - July 1969 (companion to "The Ecology and Management of Forest Recreational Areas" progress reports)
- Progress reports on activities in Itasca State Park under the project "The Ecology and Management of Forest Recreational Areas" (1969-70, 1970, 1969-71, 1971-72, 1972-73)
- A Proposal for an Experimental Burn in Itasca State Park (1972 regarding Squaw Lake West). Also, "Changes/additions to..."

- Letter to Dennis Gardner, Nov. 6, 1972 (Henry Hansen)
- University of Minnesota Research in Itasca State Park, 1973, Research Studies (Part III).
- The Itasca Park Prescribe Burn—May 12, 1975 (E. Wroe, 1975, 3 page report on the Squaw Lake West burn)
- Memo to H. L. Hansen, Aug. 18, 1975 (W. A. Patterson, 1975, his summer 1975 field observations of Squaw Lake West)
- Forestry Demonstration Area in Itasca State Park (Henry Hansen, a draft for the interpretive brochure)

<u>Meetings, etc.</u>
- Paul Rundell, personal communication (1994-1996)
- Vilis Kurmis, personal communication (1995)
- Duane Hanson, personal communication (1994 Forestry class field trip at Itasca)
- Craig Vansickle of Badoura nursery, personal communication (1994 phone conversation)
- Direct observation

<u>Student Papers</u>
- Pine Regeneration Survey, Dump Sites (Ed Musielewicz, *et al.* 1988. Unpublished forestry student report, 9-13-88, Itasca Library)

Appendix 2: Species names and codes

Tree and shrub species used in the database and this thesis. The first listed common name is preferred.

Form	ScientificName	CommonNames	SpeciesID
Shrub	*Corylus americana*	**American hazel**	AH
Shrub	*Corylus cornuta*	**Beaked hazel**	BH
Shrub	*Corylus* spp.	**Hazel**, Hazelnut	HAZEL
Shrub	*Prunus virginiana*	**Choke cherry**	CC
Shrub	*Viburnum rafinesquianum*	**Arrowwood**	AW
Tree	*Acer rubrum*	**Red maple**	RM
Tree	*Angiospermae*	**Hardwoods**	HARD
Tree	*Betula papyrifera*	**Birch**, Paper birch	PB
Tree	*Gymnospermae*	**Conifers**	SOFT
Tree	*Larix laricina*	**Tamarack**	TM
Tree	*Ostrya virginiana*	**Ironwood**, Hop hornbeam	IW
Tree	*Picea glauca*	**White spruce**	WS
Tree	*Pinus banksiana*	**Jack pine**	JP
Tree	*Pinus resinosa*	**Red pine**, Norway pine	RP
Tree	*Pinus* spp.	**Pines**	PINE
Tree	*Pinus strobus*	**White pine**	WP
Tree	*Populus grandidentata*	**Big-tooth aspen**	BgA
Tree	*Populus tremuloides*	**Trembling aspen**, Aspen, Popple, Quaking aspen	QA
Tree	*Populus* spp.	**Aspen**	ASPEN
Tree	*Prunus serotina*	**Black cherry**	BC
Tree	*Quercus alba*	**White oak**	WO
Tree	*Quercus macrocarpa*	**Bur oak**	BO
Tree	*Quercus rubra*	**Red oak**	RO
Tree	*Quercus* spp.	**Oaks**	OAK
Tree	*Thuja occidentalis*	**White cedar**	CEDAR

Appendix 3: Treatment detail tables and their attributes

Tree Removal

(Species cut and approximate % of each species cut are entered in another table, and remaining overstory and woody understory species and density are entered in the Species Density table.)

Machine: How trees were removed. Name of machine (or "heavy," "light"), or "horse"

Physical Disturbance

Tool: Name of machine or tool (*e.g.*, Bracke Scarifier)

Size: Diameter of scalp or release area or width of furrow, in feet.

Percent area: Percent of total site area disturbed.

Slash: Fate of slash (*e.g.*, windrowed, piled, broken and scattered, removed).

Soil: Fate of disturbed soil, including sod, duff, and ground vegetation (*e.g.*, humus removed)

Woody: Fate of woody understory species (shrubs and saplings) in treated areas (*e.g.*, uprooted).

Fire

Crown kill: Percent (by area) of trees killed by crowning.

Crown scorch: Percent of the canopy which was scorched.

Shrub mortality: Percent shrubs killed.

Soil: Percent of the treated area with organic soil consumed.

Surface: Percent of the treated area with damage to surface litter and vegetation.

Chemical

Trade Name: Name brand of herbicide (*e.g.*, Roundup), selected from a lookup table.

Method: Method of application: Aerial, Broad from ground, Spot

Dosage: Dosage of active ingredient in lbs./acre.

Propagation

(Species & densities are listed in the Species Density table)

Mechanical?: Was the propagation mechanical (or by hand)?

Tool: What machine or hand-tool was used?

Chemical: Were the seeds chemically treated?

Spacing: If seeding, was it broadcast or spot? If planting, is the spacing random, regular, or did the planters fill in gaps?

Nursery: Nursery or other source from which seeds or seedlings were obtained.

GeographicSource: Description of geographic area from which seeds were collected.

Exclosure

Height: Height of the fence in feet.

Rabbit: Is the fence reinforced with rabbit fencing?

Tree Protection

Percent treated: Percent of trees receiving the protection.

Monitor

Method: Methods used (relevé, plot sampling, etc.)

Plot size: Size of plot used for sampling, in acres.

Appendix 4: Treatment units

Fifty-nine treatment units were selected for analysis. Treatment units which belong to the same supersite have the same first 3 letters in their name code, but they are not combined in any way for most analyses. The sizes of the units and the portions sampled are approximate. Estimates of pine regeneration density are given for each species of pine (RP = red pine = *Pinus resinosa,* WP = white pine = *Pinus strobus*, JP = jack pine = *Pinus banksiana*) and for all 3 pines. The numbers in parentheses are densities when 1-year-old seedlings are included. A-status (promising) and B-status (medium-status) units are marked in the right-most column but C-status (unpromising) units are not.

Treatment Unit		Size	Sampling			Pine regeneration density (pines/acre)				Stat-
ID	Name	(acres)	Year	Acres	%	RP	WP	JP	Total	us
BP1H	Big Pine 1–Herbicide	116	1995	1	1%	0	0	0	0	
BP1Y	Big Pine 1–Unburned	52	1995	0.5	1%	0	0	0	0	
BP2	Big Pine 2	197	1994*	--	--	0	0	0	0	
BP3D	Big Pine 3–Dry	80	1995	0.3	<1%	0	0	0	0	
BP3U	Big Pine 3–Unplanted	150	1995	0.5	<1%	0	0	0	0	
CC2F	CCC Reproduction Plot #2–Fenced	3.15	1988*	--	--	0	0	0	0	
CC2U	CCC Reproduction Plot #2–Unfenced	0.2	1988*	--	--	0	0	0	0	
CC3	CCC Reproduction Plot #3	2.1	1988*	--	--	0	0	0	0	
CFOC	Centennial Forest–Control	0.5?	1995	.25?	50%	0	0	0	0	
CFOF	Centennial Forest–Fenced	11.5?	1995	0.3	3%	18 (24)	0 (6)	152 (167)	170 (196)	B
DS21	Demonstration Spray #2A	1	1996	2.6	100%	19 (20)	15	0	34 (35)	
DS22	Demonstration Spray #2B	1	1996	0.04	4%	0	49 (73)	0	49 (73)	
DS3	Demonstration Spray #3	3.15	1996	1	31%	44	9	0	53	
ECSE	East Contact Station–East	5?	1995	0.1	3%	92 (98)	44 (65)	468	604 (631)	A
ECSU	East Contact Station–Unfenced	1?	1995	0.5?	50%	0	0	0	0	
ECSW	East Contact Station–West	2?	1995	0.1	3%	92 (98)	44 (65)	468	604 (631)	A
EPE	East Park Entrance	1?	1996	0.1	10%	301	0	156	457	A
FDAM	Forestry Demonstration Area–Monitored	2	1970*	--	--	842	0	6	848	A
HNE	Henry Hansen Northeast	6	1995	0.2	3%	181 (187)	0	0	181 (187)	A
HSE	Henry Hansen Southeast	5	1995	0.1	2%	600	0	0	600	A
HPL	Headwaters Parking Lot	6	1995*	0.03*	0.5%*	256	0	0	256	A

(cont.)

(continued from prev. page)

Treatment Unit		Size	Sampling			Pine regeneration density (pines/acre)				Stat-
ID	Name	(acres)	Year	Acres	%	RP	WP	JP	Total	us
JP1M	Jack Pine 1–Middle	5?	1996	0.1	2%	120	17 (26)	94	231 (240)	A
JP1N	Jack Pine 1–Northeast	2?	1996	0.08	4%	12	0 (12)	239	251 (263)	A
JP1U	Jack Pine 1–Unfenced	4?	1996	0.3	7%	90	0 (3)	45	135 (139)	
JP1Y	Jack Pine 1--Fenced & Sprayed	20?	1996	0.3	2%	237 (246)	0 (21)	159	396 (426)	A
JPDC	Jack Pine Demonstration Area–Control	1?	1996	0.05	5%	110	92	18	221	B
JPDF	Jack Pine Demonstration Area–Fenced	3?	1996	0.2	5%	221	246 (309)	152	619 (682)	A
JR2	Jack Pine Restoration #2	34?	1996	0.4	1%	0	.3	0	3	
LAT	Lake Alice Trail	1.6	1996	0.06	4%	318 (334)	17 (33)	0	334 (368)	A
LBAC	Lagoon Burn Area–Control	2?	1996	0.1	5%	20	39 (572)	10	69 (602)	
LBAF	Lagoon Burn Area–Fenced	5?	1996	0.06	1%	31	16	0	47	
LGEF	Sewage Lagoon East–Fenced	1.8	1995	0.08	4%	219	0	0	219	A
LGEU	Sewage Lagoon East–Unfenced	32.2	1995	0.3	1%	3	0	0	3	
LGWM	Sewage Lagoon West–Main	24.75	1995	0.4	2%	5	0	0	5	
LGWS	Sewage Lagoon West–Seeded	1.25	1995	0.02	2%	5	0	0	5	
MIF	Miller's Field	3.5?	1996	0.1	4%	1217 (1225)	0	8	1225 (1233)	A
MIR	Miller's Old Road	1?	1996	1?	100%	52 (57)	33 (48)	87 (94)	172 (199)	B
MLEF	Mary Lake Deer Exclosure–Fenced	2.5	1984*	--*	--*	16	643	0	659	A
MLEU	Mary Lake Deer Exclosure–Unfenced	1.7	1984*	--*	--*	4	235	0	239	
OBRC	Old Bemidji Road Area–Cut	3	1996	0.1	3%	98	0	0	98	A
OPE	Old Park Entrance	10	1996*	?*	~25%*	0	0	0	0	
R13	Red Pine 13	15	1996	0.2	2%	114	9	145	268	B
RHH	Roy Hemrick Homesite	8	1996	0.1	2%	0	35	0	35	
RP4	Red Pine 4	4	1996	0.06	2%	0	0	65	65	

(cont.)

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Treatment Unit		Size	Sampling			Pine regeneration density (pines/acre)				Stat-
ID	Name	(acres)	Year	Acres	%	RP	WP	JP	Total	us
SLEE	Squaw Lake[§] East–East	15	1995	0.2	2%	0	0	0	0	
SLEN	Squaw Lake[§] East–North	6	1995	0.09	2%	0	0	0	0	
SLER	Squaw Lake[§] East–Remainder	19	1995	0.3	2%	0	0	0	0	
SLEW	Squaw Lake[§] East–West	6	1995	0.09	2%	0	0	0	0	
SLW1	Squaw Lake[§] West–1	11	1995	0.08	1%	0	0	0	0	
SLWM	Squaw Lake[§] West–Main	195	1995	1.4	1%	0	0	0	0	
SLWS	Squaw Lake[§] West–South	9	1995	0.06	1%	0	0	0	0	
SLWW	Squaw Lake[§] West–West	5	1995	0.04	1%	0	0	0	0	
SMF	Sawmill Field	22	1996	0.2	1%	154 (160)	62 (68)	6	221 (234)	A
TPFE	Trading Post Field–East	2.5?	1996	0.08	3%	0	38 (51)	0	38 (51)	
TPFW	Trading Post Field–West	7.5?	1996	0.2	2%	174 (192)	29 (64)	0	204 (256)	B
TSTD	Two Spot Trail Burn–Direct Seeded	0.018	1996	<0.01	2%	0	0	0	0	
TSTM	Two Spot Trail Burn–Main	30	1996	0.5	2%	0	0	0	0	
WPKC	White Pine Knob–Control	3	1995	0.5	16%	0	0	0	0	
WPKF	White Pine Knob–Fence	5	1995	1.5	30%	0 (1)	3 (5)	0	3 (5)	

[§]The name of Squaw Lake was changed to "Lake Ozawindib" circa 1996.

*These units were sampled by different methods, as described in the text.

Appendix 5: Approximate locations of treatment units

Only Supersite IDs are shown, which are the first 3 letters of the treatment unit ID. Supersites contain 1 or more treatment units. See Appendix 4 for treatment unit names and sizes.